AGRONOMIC EVALUATION OF CROP GEOMETRY AND IRRIGATION STRATEGIES ON PERFORMANCE OF SPRING MAIZE (*Zea mays* L.)

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Agronomy

By

Chakravarthy Thejesh

Registration Number: 12014309

Supervised By

Dr. Bhupendra Mathpal (20525)

Department of Agronomy (Associate Professor)

School of Agriculture

Co-supervised By

Dr. Barkha (26023)

Department of Agronomy (Assistant Professor)

School of Agriculture

LOVELY PROFESSIONAL UNIVERSITY, PUNJAB

2024

DECLARATION

I, hereby declared that the presented work in the thesis entitled **"Agronomic evaluation of crop geometry and irrigation strategies on performance of spring maize (*Zea mays* L.)"** in fulfilment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision of **Dr. Bhupendra Mathpal (20525)**, working as **Associate Professor**, in the **Department of Agronomy, School of Agriculture** of Lovely Professional University, Phagwara, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

(Signature of Scholar)

Name of the scholar: **Chakravarthy Thejesh**

Registration No.: **12014309**

Department of Agronomy,

School of Agriculture

Lovely Professional University,

Punjab, India

CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled **"Agronomic evaluation of crop geometry and irrigation strategies on performance of spring maize (*Zea mays* L.)"** submitted in fulfillment of the requirement for the reward of degree of **Doctor of Philosophy (Ph.D.)** in the Department of Agronomy, School of Agriculture, is a research work carried out by **Chakravarthy Thejesh (Registration no: 12014309)**, is bonafide record of his original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

(Signature of Supervisor)

Name of supervisor: **Dr. Bhupendra Mathpal**

Associate Professor

Department of Agronomy

School of Agriculture

Lovely Professional University

(Signature of Co-Supervisor)

Name of Co-Supervisor: **Dr. Barkha**

Assistant Professor

Department of Agronomy

School of Agriculture

Lovely Professional University

ABSTRACT

Thesis title: **"Agronomic evaluation of crop geometry and irrigation strategies on performance of spring maize (*Zea mays* L.)"**

The current investigation was executed at the research farm, Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, Punjab, during the spring season of the year 2022 and 2023 to accomplish the three objectives. The first objective was to evaluate the influence of irrigation strategies and crop geometry on the growth as well as the yield of spring maize. The second objective was to investigate the impact of irrigation strategies and crop geometry in the improvement of quality and soil parameters of spring maize. The third objective was to find out an efficient treatment in terms of monetary advantage. The soil of experimental site was sandy loam in texture. The soil was slightly alkaline (7.95 pH), with a normal range of electrical conductivity (0.135 d/Sm), low in available nitrogen (207.98 kg/ha), high in phosphorous (23.80 kg/ha) and moderate in potassium (166.37 kg/ha). The research trial was carried out in split-plot design with three main plots consisting of different levels of hydrogel - H_1: without hydrogel (0 kg/ha); H_2: 1.5 kg/ha and H_3: 3 kg/ha and four sub-plots consisting of different crop geometries C_1: normal spacing (70 × 25 cm); C_2: paired-row spacing (55 - 85 × 25 cm); C_3: normal spacing with the seed capsule (70 × 25 cm) and C_4: paired-row spacing with the seed capsule (55 - 85 × 25 cm). By using main plots and subplots, twelve treatment combinations were prepared which were replicated thrice. Regarding the different levels of hydrogel and crop geometric strategies, the application of treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) has shown a substantial influence on the improvement of growth and the yield parameters. Maximum growth attributes like plant height (19.0 cm, 75.2 cm, 148.9 cm and 192.1 cm), no. of leaves per plant (8.2, 10.8, 16.3 and 14.7), stem girth (3.5 cm, 6.4 cm, 8.5 cm and 10.4 cm) and stem diameter (1.13 cm, 2.1 cm, 2.7 cm and 3.3 cm) at 25, 50, 75 and 100 DAS respectively was recorded. Whereas the superior yield parameters like no. of cobs per plant (2.0 and 1.9), cob length (cm) (19.8 cm and 18.6 cm), cob girth (cm) (15.5 cm and 14.7 cm), cob weight with the husk (213.4 g and 204.5 g), weight of cob without the husk (165.5g and 159.3 g), no. of rows per cob (12.9 and 12.6), no. of grains per row of cob (31.8 and 31.3), no. of grains per cob (409.5 and 393.1), seed index (100 grains weight) (31.9 g and 31.8 g), grain yield (9.5 t/ha and 8.9 t/ha), stover yield (16.3 t/ha and 15.5 t/ha), biological yield (26.2 t/ha and 25.1 t/ha) and harvest index (36.1% and 35.5%) were recorded under H_3 ((3 kg/ha) and C_4 (paired-row spacing with the seed capsule (55 - 85 × 25 cm) respectively. In the mean data, an increase of grain and stover yield by 40.42% and 28.49% respectively was recorded over control. The same treatment efficiently enhanced the N, P and K uptake in the grain and stover of spring maize. The maximum N uptake in grain (62.7 kg/ha and 61.4 kg/ha), stover (48.4 kg/ha and 46.4 kg/ha) and total uptake (111.0 kg/ha and 107.7 kg/ha) were recorded under H_3 (3 kg/ha) and C_4 (paired-row spacing with the seed capsule (55 - 85 × 25 cm) respectively. The maximum P uptake in grain (14.7 kg/ha and 14.0 kg/ha), stover (13.0 kg/ha and 12.3 kg/ha) and total uptake (27.7 kg/ha and 26.3 kg/ha) were recorded under H_3 (3 kg/ha) and C_4 (paired-row spacing with the seed capsule (55 - 85 × 25 cm) respectively. The maximum K uptake in grain (19.3 kg/ha and 18.7 kg/ha), stover (85.9 kg/ha and 83.9 kg/ha) and total uptake (105.3 kg/ha and 102.6 kg/ha) were recorded under H_3 (3 kg/ha) and C_4 (paired-row spacing with the seed capsule (55 - 85 × 25 cm) respectively. The highest protein content (11.3 % and 10.7%) and grain appearance score (2.6 and 2.3) were recorded under the H_3 (3 kg/ha) and C_4 (paired-row spacing with the seed capsule (55 - 85 × 25 cm) respectively. While the lowest growth, yield and quality parameters were recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). The highest available nutrient status of N (176.5 kg/ha and 178.9 kg/ha); P (18.2 kg/ha and 18.5 kg/ha) and K (130.3 kg/ha and 133.6 kg/ha) after harvest was recorded under the H_3 (3 kg/ha) and C_4 (paired-row spacing with the seed capsule (55 - 85 × 25 cm). The application of hydrogel has significantly improved the soil moisture regime. The hydrogel application at 3 kg/ha has reduced the irrigations and the longest irrigation intervals of 12.1 and 18.8 days were recorded when compared to the control (hydrogel at 0 kg/ha) (7.8 and 11.7 days) in 2022 and 2023 respectively. Maximum gross (Rs. 1,83,480/ha) and net return (Rs.1,26,392/ha) were obtained by the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule. The maximum benefit-cost ratio (2.54) and (3.20) resulted under T_{10} (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)) in 2022 and 2023 respectively, while the lowest benefit-cost ratio resulted under T_3 (hydrogel 0 kg/ha + normal spacing (70 ×25 cm) with the seed capsule).

Keywords: Hydrogel, seed capsule, biofertilizers, crop geometry, spring maize

(Dr. Bhupendra Mathpal)
Advisor

(Chakravarthy Thejesh)
Author

ACKNOWLEDGEMENT

*First and foremost, I bow my head in reverence and sincerely express my gratitude to my lord **"Sri Venkateshwara Swamy"** and my Guru **"Sai Baba",** the most gracious, merciful, and compassionate being. It is through their grace, glory and boundless blessings, that accompanied me in all the endeavours and the benevolence received. I was able to muster the courage to successfully complete this degree at certain difficult times.*

This endeavour is the result of years of hard work, whereby I am highly indebted to many people who directly and indirectly helped me with its successful completion

*I would like to express my sincere gratitude to my advisor, **Dr. Bhupendra Mathpal** Associate Professor in the Department of Agronomy at Lovely Professional University in Punjab, for his efficient supervision, invaluable advice, scholastic guidance, untiring assistance, continuous encouragement with wise counsel and helpful criticism in every aspect from the very beginning to the completion of this research and manuscript preparation. Without his keen supervision and constructive suggestions, it would become very hard for me to complete this thesis. I owe him my undying love, respect, and sincere gratitude for his zeal, support, and kindness.*

*I would like to express my gratitude to my co-advisor, **Dr. Barkha Singh**, Assistant Professor in the Department of Agronomy at Lovely Professional University in Punjab, for providing valuable suggestions and inputs in improving the quality of the manuscript.*

*I would like to thank **Dr. Rupinder Singh Ahluwalia**, Assistant Professor in the Department of Horticulture at Lovely Professional University, Punjab for his impeccable help and valuable suggestions during the field trials. My sincere thanks to **Dr. Tarun Sharma**, Assistant Professor in the Department of Agronomy, Lovely Professional University Punjab for his guidance and moral support during the completion of the course. My sincere thanks to **Dr. Supreet Sajan**, former Assistant Professor in the Department of Agronomy, Lovely Professional University Punjab for his guidance and support.*

*There are no words to express my feelings of adoration, love, respect and obligation to my beloved parents, who moulded me into what I am now. They taught me to lead an obedient, trustworthy and well-planned life, which constantly guided me as a lighted lamp towards my destination. I humbly and respectfully thank my beloved mother, **Smt. Vemula Thirumala Devi**, my father **Sri. Chakravarthy Leela Mohan Rao** and my brother **Chakravarthy Kalyan** for their unwavering support, encouragement, and inspiration as I pursued my higher education.*

This research would not have been possible without the kind time, effort, wisdom, and experiences that my friends ***Simarjot Singh, Sai Kumar Reddy, Sreethu, Lalit Saini, Amit Kumar*** *and* ***Shyam Sundar*** *have given me. I will always be thankful for their emotional support and motivation. I am grateful to my brothers* ***Rakesh Uttara, Veera Sai, Pavan, Sri Hari and their friends*** *who have helped me during my field trials selflessly.*

I will always be grateful to everyone who supported me, whether directly or indirectly. Lastly, I would like to express my gratitude to Lovely Professional University, Punjab, for providing me with the information I needed for my investigation. Not all have been acknowledged, but none are overlooked.

Date: 31st, May, 2025 ***Chakravarthy Thejesh***

Place: *Phagwara, Punjab*

TABLE OF CONTENTS

Chapter	Title	Page no.
	ABSTRACT	i-ii
	ACKNOWLEDGEMENT	ii-iv
	TABLE OF CONTENTS	v-viii
	LIST OF TABLES	v-viii
	LIST OF FIGURES	viii
	LIST OF APPENDICES	ix
	LIST OF ABBREVIATIONS	x-xii
1	INTRODUCTION	1-5
2	REVIEW OF LITERATURE	6-36
3	MATERIALS AND METHODS	37-53
4	RESULTS AND DISCUSSION	54-131
5	SUMMARY AND CONCLUSION	132-137
	BIBLIOGRAPHY	138-174
	APPENDICES	xiii-xix

LIST OF TABLES

Table no.	Description	Page no.
2.1	Types of hydrogels based on the grafting technology suitable for agriculture	14
3.1	Chemical properties of soil at the experimental site	38
3.2	Experimental site cropping history	38
3.3	Experimental details	40
3.4	Experimental factors	40
3.5	Treatment combinations of the experiment	41
3.6	Chronological record of agro-techniques implemented (Calendar of operations) during the experiment	45

3.7	Chronological record of irrigation schedule during the experiment	46
4.1	Impact of different hydrogel levels and crop geometric strategies on the plant height (cm) of spring maize at 25, 50, 75 and 100 DAS	56
4.2	Impact of the interaction of different hydrogel levels and crop geometric strategies on the plant height (cm) of spring maize at 25 DAS	57
4.3	Impact of the interaction of different hydrogel levels and crop geometric strategies on the plant height (cm) of spring maize at 50 DAS	58
4.4	Impact of the interaction of different hydrogel levels and crop geometric strategies on the plant height (cm) of spring maize at 75 DAS	59
4.5	Impact of the interaction of different hydrogel levels and crop geometric strategies on the plant height (cm) of spring maize at 100 DAS	60
4.6	Influence of different hydrogel levels and crop geometric strategies on the number of leaves of spring maize at 25, 50 75 and 100 DAS.	64
4.7	Impact of the interaction of different hydrogel levels and crop geometric strategies on the number of leaves of spring maize at 25 DAS	65
4.8	Impact of the interaction of different hydrogel levels and crop geometric strategies on the number of leaves of spring maize at 50 DAS	66
4.9	Impact of the interaction of different hydrogel levels and crop geometric strategies on the number of leaves of spring maize at 75 DAS	67
4.10	Impact of the interaction of different hydrogel levels and crop geometric strategies on the number of leaves of spring maize at 100 DAS	68
4.11	Influence of different hydrogel levels and crop geometric strategies on the stem girth (cm) of spring maize at 25, 50, 75 and 100 DAS	73
4.12	Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem girth of spring maize at 25 DAS	74
4.13	Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem girth of spring maize at 50 DAS	75
4.14	Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem girth of spring maize at 75 DAS	76
4.15	Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem girth of spring maize at 100 DAS	77
4.16	Influence of different hydrogel levels and crop geometric strategies on the stem diameter (cm) of spring maize at 25, 50, 75 and 100 DAS	78

4.17	Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem diameter of spring maize at 25 DAS	79
4.18	Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem diameter of spring maize at 50 DAS	80
4.19	Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem diameter of spring maize at 75 DAS	81
4.20	Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem diameter of spring maize at 100 DAS	82
4.21	Influence of different hydrogel levels and crop geometric strategies on the yield parameters of spring maize	89
4.22	Interaction effect of different hydrogel levels and crop geometric strategies on the weight of cob with husk and without husk (g) of the spring maize	90
4.23	Influence of different hydrogel levels and crop geometric strategies on the yield parameters of spring maize	97
4.24	Influence of different hydrogel levels and crop geometric strategies on the yield parameters of spring maize	99
4.25	Impact of different hydrogel levels and crop geometric strategies on the yield parameters of spring maize	101
4.26	Interaction effect of different hydrogel levels and crop geometric strategies on the grain yield (t/ha) of the spring maize	102
4.27	Interaction effect of different hydrogel levels and crop geometric strategies on the stover yield (t/ha) of the spring maize	105
4.28	Interaction effect of different hydrogel levels and crop geometric strategies on the biological yield (t/ha) and harvest index of the spring maize	108
4.29	Influence of different hydrogel levels and crop geometric strategies on the available soil N, P and K (kg/ha) at harvest	111
4.30	Chronological record of irrigation schedule and irrigation intervals during the experiment	113
4.31	Influence of different hydrogel levels and crop geometric strategies on the N uptake (kg/ha) of spring maize	122

4.32	Influence of different hydrogel levels and crop geometric strategies on the P uptake (kg/ha) of spring maize	123
4.33	Influence of different hydrogel levels and crop geometric strategies on the K uptake (kg/ha) of spring maize	124
4.34	Influence of different hydrogel levels and crop geometric strategies on the protein content (%) and grain appearance score of spring maize	127
4.35	Effect of different hydrogel levels and crop geometric strategies on the monetary parameters of the spring maize	130

LIST OF FIGURES

Fig no.	Description	Page no.
1.1	a. Major maize-producing states in India; b. Top 10 maize-producing countries; c. Maize production in India (2021-22)	2
2.1	Food production loss events over the past decades	8
2.2	Scenario of the months in a year in which water scarcity is > 100%	8
2.3	Influence of climate change on agricultural farm productivity (%)	9
2.4	Comparison of disaster-induced production losses with annual intake of kilo calories, iron, zinc and calcium uptake per year	10
2.5	Hydrogel in dry and swollen stage; diagrammatic representation of hydrogel in soil	11
2.6	Methods of biofertilizer application	25
2.7	Beneficial aspects of plant growth-promoting bacteria	28
3.1	Location of the experimental trial site	37
3.2	Layout of the experimental site	43
3.3	Plot depicting the normal spacing (70 × 25 cm)	44
3.4	Plot depicting the paired row spacing (55-85 cm × 25 cm)	44

LIST OF APPENDICES

Appendix no.	Description	Page no.
1	Weather conditions that prevailed throughout the cropping seasons of the experiment (spring season 2022 and 2023)	xiii
2	Fixed costs (₹/ha) incurred during the experiment	xiv
3	Variable costs (₹/ha) of seed capsules and hydrogel incurred during the experiment	xv
4	Variable costs (₹/ha) of irrigation incurred during the experiment	xvi
5	Total cost of cultivation (₹/ha) incurred during the experiment in 2022	xvii
6	Total cost of cultivation (₹/ha) incurred during the experiment in 2023	xviii
7	Standard curve of BSA during protein content assessment.	xix
8	ANOVA tables	xx-lviii

LIST OF ABBREVIATIONS		
S. No	**Abbreviation**	**Full name**
1	ABA	Abscisic acid
2	AMF	Arbuscular mycorrhizal fungi
3	APEDA	Agricultural and Processed Food Products Export Development Authority
4	ATP	Adenosine triphosphate
5	AWT	Average weekly temperature
6	B:C	Benefit: cost
7	BGA	Blue-green algae
8	BSA	Bovine serum albumin
9	Bt	Bacillus thuringiensis
10	CD	Critical difference
11	DACNET	Department of agriculture and cooperation network
12	DAP	Diammonium phosphate
13	DAS	Days after sowing
14	EC	Electrical conductivity
15	EDTA	Ethylenediamine tetraacetic acid
16	FA	Fulvic acid
17	FAO	Food and Agriculture Organisation
18	FAOSTAT	Food and Agriculture Organization statistics
19	GA	Gibberellic acid
20	GOI	Government of India
21	H	Hydrogen
22	HA	Humic acid
24	HI	Harvest index
25	HS	Humic substances
26	IAA	Indole acetic acid
27	IARI	Indian Agricultural Research Institute
28	ICAR	Indian Council of Agricultural Research
29	IFFCO	Indian farmers fertilizer cooperative limited

30	IIMR	Indian Institute of Maize Research
31	IISR	Indian Institute of Spices Research
32	INM	Integrated nutrient management
33	IPCC	Intergovernmental panel on climate change
34	IUPAC	International union of pure and applied chemistry
35	K	Potassium
36	KEL plus	KEL plus digestion unit
37	KSB	Potassium solubilizing Bacteria
38	LDC	Least developed countries
39	LMIC	Low to middle-income countries
40	LPU	Lovely Professional University
41	MOP	Muriate of potassium
42	MSL	Mean sea level
43	MST	Ministry of science and technology
44	MT	Metric ton
45	N	Nitrogen
46	NAA	Naphthaleneacetic acid
47	NPK	Nitrogen, phosphorous and potassium
48	NRDC	National research development corporation
49	NS	Non-significant
50	NTC	National toxicology center
51	O	Oxygen
52	OA	Organic acids
53	OC	Organic carbon
54	OM	Organic matter
55	P	Phosphorous
56	PGP	Plant growth promoting
57	PGPR	plant growth-promoting rhizobacteria
58	pH	Negative logarithm of H^+ ion concentration
59	PMB	Phosphorous-mobilizing biofertilizers
60	PMH-10	Punjab maize hybrid-10
61	PSB	Phosphate solubilizing bacteria

62	PWP	Permanent wilting point
63	RDA	Recommended dietary allowance
64	ROS	Reactive oxygen species
65	S	sulphur
66	SAP	Super absorbent polymer
67	SAR	Systemic acquired resistance
68	Sem	Standard error of the mean
69	SMW	Standard metrological week
70	UN	United Nations
71	UNEP	United Nations Environment Programme
72	USA	United States of America
73	UV	Ultraviolet
74	Var.	Variety
75	WHC	Water holding capacity
76	WHO	World Health Organisation
77	WRC	Water retention capacity
78	WUE	Water use efficiency

LIST OF UNITS		
S. no	**Unit**	**Description**
1	%	Percentage
2	₹	Rupee
3	cm	Centimetre
4	g	Gram
5	ha	Hectare
6	kg/ha	Kilogram per hectare
7	m	Meter
8	m^2	Square meter
9	ml	Milliliter
10	mm	Millimetre
11	nm	Nanometer

LIST OF CHEMICAL FORMULA		
S. no	**Formula**	**Compound**
1	CH_4	Methane
2	CO_2	Carbon dioxide
3	Fe_3^+	Ferric oxide
4	$H_2PO_4^-$	Dihydrogen phosphate
5	H_2SO_4	Sulfuric acid
6	H_3PO_4	Phosphoric acid
8	$HClO_4$	Perchloric acid
9	HNO_3	Nitric acid
10	HPO_4^-	Hydrogen phosphate
11	$K_2Cr_2O_7$	Potassium dichromate
12	$KMnO_4$	Potassium permanganate
13	N_2O^-	Nitrous oxide
14	NaCl	Sodium chloride
15	NaH_2PO_4	Monosodium phosphate
16	$NaHCO_3$	Sodium bicarbonate
17	NaOH	Sodium hydroxide
18	NH_3	Ammonia
19	NH_4^+	Ammonium ion
20	NH_4OAc	Ammonium acetate
21	$(NH_4)_2Fe(SO_4)_2 \cdot 6H_2O$	Ferrous ammonium sulfate hexahydrate
22	NO_2	Nitrogen dioxide
23	NO^{-3}	Nitrate
24	O_3	Trioxygen or oxygen
25	$SnCl_2$	Tin dichloride or stannous chloride

CHAPTER – I
INTRODUCTION

CHAPTER - 1

INTRODUCTION

Maize (*Zea mays* L.) is a crucial cereal crop which is having a wide range of adjusting nature under diverse climatic situations. Due to its high-yielding potential, the crop is often referred to as ***"Queen of Cereals".*** It is cultivated in very diverse conditions including temperate, tropical, and subtropical areas that are up to 3,000 metres above sea level and is under cultivation in more than 165 countries and accounts for nearly 40% of the worldwide grain production. The USA is the leading producer of maize which contributed to about 30% of the total global maize production in the year 2020 and a major contributor to the US economy **(Agricultural and Processed Food Products Export Development Authority [APEDA], 2022)** and maize accounts 10% of total grain production in India **(Maize Outlook, 2021)**. With a global productivity of 5823.3 kg/ha and production of 1148 million tonnes, it is cultivated on approximately 197 million hectares **(Food and Agriculture Organization Corporate Statistical Database [FAOSTAT], 2019)**. Each component of maize plant has fiscal value: the leaves, stalk, tassel, grain, and cob are utilised to make a wide variety of commodities, both edible and non-edible. During the year 2022-23, the nation's maize production has soared to 346.13 lakh tonnes from 337.3. lakh tonnes in the preceding year with a surplus of 8.83 lakh tonnes **(Anonymous, 2023).** India has exported maize of 3,453,680.58 MT in 2022-23 which fetched nearly nine thousand crores. The major export destinations are the neighbouring Asian countries like Bangladesh, Nepal Sri Lanka, Vietnam and Malaysia **(Anonymous, 2022)**.

In northern India, wheat and rice are the most significant crops grown. In the Indo-Gangetic plains of the Indian sub-continent, the constant adoption of the rice-wheat cropping system has led to abundant antagonistic effects **(Chhiba, 2008)** including soil health deterioration, severe groundwater exhaustion and the advent of new insects, pests, diseases and weed infestation which deserve to necessitate crop diversification. Because of the abundance of food grains, governmental institutions and organizations are creating awareness to transform the cropping pattern and adopt a substitute crop like maize. Transforming the cropping pattern with maize will help to effectively implement the diversification of crops **(Sharma *et al.,* 2014)** with extensive usage of maize in the livestock as well as the poultry feed to manufacture corn flakes, starch and glucose-based products for human consumption. Adoption of spring maize cultivation will fulfil the green cob and silage demand in the early and mid-summer can be a profit-making which can bring financial stability for the next season to the farmer and also uplift the goals of crop diversification.

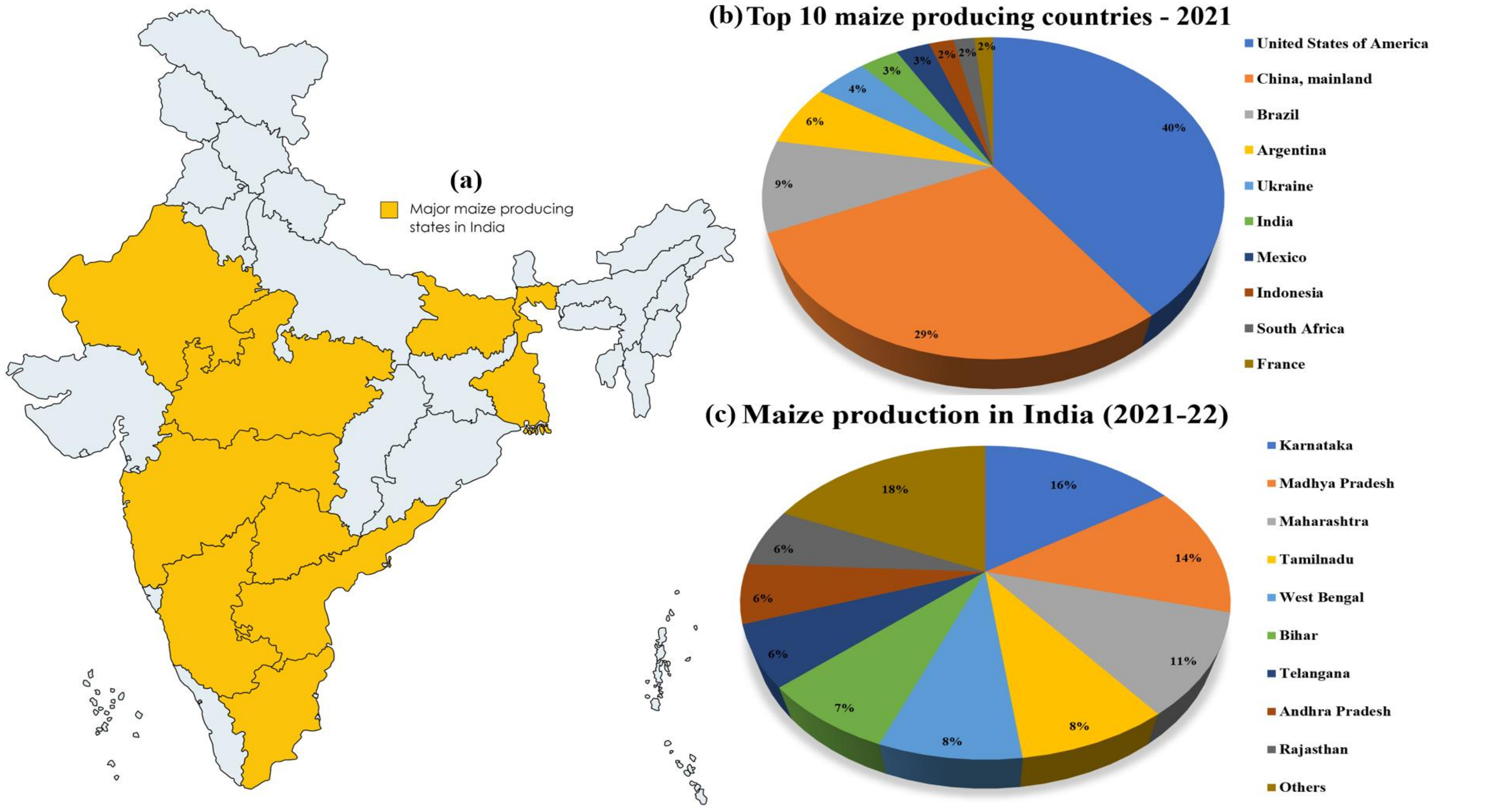


Fig 1. a. Major maize-producing states in India **(APEDA, 2022);** b. Top 10 maize-producing countries **(FAOSTAT, 2021);** c. Maize production in India (2021-22) **(Anonymous, 2022)**

According to **Intergovernmental Panel on Climate Change (IPCC, 2007)** studies, climate change is anticipated to impact agriculture by raising the threat of hunger and water shortage. It will lead to the melting of glaciers. Due to climate change in India, the ease of access to fresh water in various river basins has decreased **(Gosain *et al.,* 2006).** Under this scenario, water scarcity in agriculture has been impacted. Compared to the domestic sector (5%) and the industrial (10%), the agriculture sector (85%) consumes the largest quantity of water. Numerous initiatives are being intended as well as implemented to enhance the water-use efficiency in agriculture. Farmers are employing various techniques to manage the shortage of water, such as mulching, ridge furrow methods, minimum tillage, sprinklers, drip systems, mechanical water harvesting techniques, and various other management strategies. The employment of new technology like hydrogel is one such method to enhance water-use efficiency **(Kalhapure *et al.,* 2016)**.

Hydrogel is a synthetic polymer; it is insoluble and hydrophilic. After the amendment of hydrogel in the soil it can absorb a huge amount of water when available in the form of rain or irrigation **(Schacht, 2004).** Hydrogel has an immense role in regions where the chance for irrigation is inadequate and boosts water accessibility during crop establishment. The hydrogel can absorb and hold onto water up to 80–180 times its initial volume, while as stated by **Kalhapure *et al.* (2016),** it can absorb 400 times its actual weight. The hydrogel amends different soil physical properties like structure, infiltration rates, density as well as soil compaction **(El-Hady & Abo-Sedera, 2006)**. Numerous reports have proved the beneficial impact of the hydrogel on crop performance and the properties of soil. The hydrogel application in alluvial and sandy loam soil drastically influenced the hydrological properties of the soil like field capacity, saturated hydraulic conductivity and plant available water content **(Narjary & Aggarwal, 2016)**.

Better exploitation of agronomic techniques can define the crop yield potential. Of the benchmark agronomic practices that can imitate the crop yield potential, crop geometry and nutrient management practices are very important factors in determining yield. The light interception and CO_2 assimilation which is affected by canopy architecture can intrude on the productivity that can be changed by the plant geometry **(Reddy *et al.,* 2020)**. The planting pattern also plays a dynamic role in utilizing resources effectively. The practice of paired row planting or twin-row planting devoid of reduction in plant population has been an effective and proficient utilization of resources by crops **(Mamathashree *et al.,* 2019)**. Paired row planting in maize is a practice that is an altered one from normal. In the paired row planting, we bring the two adjacent rows are supposed to bring nearer to make them a pair and increase the spacing distance between the two pairs by maintaining the same plant-plant spacing without reducing the plant population.

The seed capsule is in the juvenile stage in terms of research and adaptation in real life by farmers. These gelatin capsules can be easily soluble and also act as a bio-stimulant in the early stage of the crop **(Wilson, 2018)**. Seed capsules act as power boosters which comprise all kinds of biofertilizers, humic acid, and neem powder which play a role as crop protectors. With intensive utilization of chemical fertilizers and plant protection measures, chemicals have endangered sustainable agriculture by declining water and soil resources and conserving the environment **(Ekin *et al.,* 2019)**. For sustainable crop production, new mechanisms have to be deployed to provide adequate nutrition without causing any harm to the ecosystem **(Panwar & Laxmi, 2005).** Biofertilizers are living microorganisms that are eco-friendly which promotes plant growth by enhancing nutrient availability to plants **(Amutha *et al.,* 2014).** It augments the nutrients through various natural processes of nutrient fixation, solubilization as well as plant growth stimulation by enhancing synthesis of the growth-promoting elements **(Vessey, 2003).** They improve the soil fertility by the atmospheric N fixation in association with the plant roots or without; solubilizing the insoluble phosphate and also by improving the mobilization of them in the soil **(Venkateshwarlu, 2008).**

Humic acid is a vital soil constituent that can enhance soil nutrient availability and enhance physio-chemical properties **(Meganind *et al.,* 2015)**. Humic acid is effective in the preservation and management element for the sustainability of the soil **(Gumus *et al.,* 2015).** It helps in the mobilization of the nutrients in the soil as well as increases their availability for the plant **(Khaled & Fawy 2011).** Humic acid has beneficial aspects like increasing the organic composition in the deficit soil, enhanced synthesis of chlorophyll, seed germination, root vitality, reduced leaching of nutrients, superior nutrient uptake, increased microbial activity, plant growth and yield **(Duary, 2020).** Neem cake powder is prepared from the crushed leaves, fruits and bark of the neem plants. Neem powder is packed with a lot of micro and macronutrients, with the slow-releasing nature of the nutrients eventually increasing soil fertility. Neem powder prevents the conversion of nitrogenous compounds to nitrogen gas that acts as a nitrification inhibitor, thereby enhancing nitrogen availability in the soil and fertilizer efficiency. Neem powder is a natural insecticide, nematicide and pesticide that can control soil-based nematodes, pathogens and diseases **(Jagadish, 2020).** Neem powder also checks the losses of the nutrients from the rhizosphere.

Research on irrigation strategies (different levels of hydrogel), crop geometric strategies (normal spacing and paired row spacing along with seed capsules) in maize is crucial in the current global scenario due to the increasing challenges of climate change and water scarcity. Maize, being a staple crop worldwide, requires efficient resource management to sustain productivity under erratic rainfall and limited water availability. Hydrogel polymers known for their water-retention properties can significantly improve soil moisture retention and reduce irrigation frequency. However, there is a lack of comprehensive studies on the optimal dosage of hydrogel, as excessive use may lead to unintended soil modifications or economic inefficiencies. Similarly, crop geometry plays a vital role in optimizing plant growth, nutrient uptake, and water-use efficiency. Traditional row spacing may not facilitate better light interception, root expansion or aeration which are critical for maximizing maize productivity. Paired row spacing aids in enhancing root interactions, improve canopy structure and facilitating better resource utilization. However, its impact under different levels of hydrogel and seed capsules as new technology remains underexplored. The combination of optimized irrigation strategies with suitable crop geometry could lead to higher productivity, improved water-use efficiency and greater climate adaptability. Addressing this research gap is essential for developing a sustainable and climate-smart maize production system that can withstand water limitations while ensuring optimal productivity and profitability for farmers. Therefore, with the view of the importance of crop geometry and irrigation strategies in spring maize, the current research was planned with the following objectives:

Objectives:

1. To evaluate the effect of irrigation strategies and crop geometry on the growth and yield of spring maize.
2. To investigate the impact of the irrigation strategies and crop geometry in the improvement of quality and soil parameters of spring maize.
3. To find out an efficient treatment in terms of monetary advantage.

CHAPTER – II

REVIEW OF LITERATURE

CHAPTER - II
REVIEW OF LITERATURE

In the current chapter, literature relevant to the current thesis entitled **"Agronomic evaluation of crop geometry and irrigation strategies on performance of spring maize (*Zea mays* L.)".** has been reviewed and discussed.

2.1. Maize production scenario

Maize (*Zea mays* L.) is cultivated worldwide as a crucial cereal crop. It is the most adaptable crop to any agro-climatic conditions. It is under cultivation in about more than 160 countries with varied soil diversity, climate and management practices that contribute to 40% of global grain production **(Parihar *et al.,* 2011).** The United States of America (USA) is the biggest producer in the world followed by China, Brazil, Argentina and Ukraine. India is the 6^{th} biggest producer of maize and ranks 4^{th} in terms of area of production. After rice and wheat, it is the 3^{rd} significant food grain crop that is grown **(FAOSTAT, 2021).** During 1950-51, maize production in India was 1.73 m tonnes, which amplified to 33.3 m tonnes by 2022-23, recording an increase of 94.80% in production **(DACNET, 2023).** The USA has the highest productivity of more than 9,600 kg/ha, two times the global average (4,920 kg/ha). The average national productivity has amplified 5.42 times, from 547 kg/ha in 1950-51 to 2965 kg/ha in 2022-23 **(Economics and Statistics, DAC& FW, GOI, 2023).**

In India, maize is cultivated as a seasonal crop in the southern peninsula, while it is confined to kharif and spring/zaid season in northern India. Kharif maize holds a maximum area of 83%, while rabi maize represents 17% area. The majority of the cultivated area in kharif maize is under rainfed conditions, which is more prone to biotic and abiotic stress and results in poor productivity (2706 kg/ha) when compared to rabi maize with higher productivity (4436 kg/ha**) (Indian Council of Agricultural Research (ICAR) - Indian Institute of Maize Research (IIMR), 2020).** Maize cultivation is undertaken in the kharif season in the northern counterparts of the country. Due to the suitable temperatures, maize is under cultivation throughout the year in the southern peninsula. Recently, as a part of crop diversification policy by the government of India, spring maize cultivation has increased in states like Punjab, Haryana and western Uttar Pradesh. In the kharif season (2023), the largest maize producer was Madya Pradesh followed by Karnataka, Rajasthan, Uttar Pradesh, Maharashtra and Telangana **(Maize Outlook, 2024).** Andhra Pradesh has the highest state productivity of maize in India, some districts like Krishna, West Godavari and Kurnool districts have recorded productivity (12t/ha) more or equal to the USA **(Economics and Statistics, DA& FW, GOI, 2023).** Maize is an important food grain crop that feeds as well as contributes to the nation's economy. Ensuring global food security is the uppermost precedence by fulfilling the needs of an ever-growing population along with the drastic negative changes in climatic conditions.

Currently, agriculture is facing various pressures like famine, droughts, high temperatures and salinity etc. in various parts of the globe. It may reach its peak because of climate change, land degradation, rapid urbanization and deforestation. According to **IPCC (2007)**, climate change probably will impact agriculture, heave the menace of hunger, dearth of water and lead to the melting of glaciers in the near future. Under these curb situations, the accessibility to fresh water and arable land resources will be at a minimal level while the population rise across the world is anticipated to touch about 9 billion by 2050 and 11.2 billion by the year 2100 **(UN, 2017).** The ease of access to fresh water in various river basins has decreased in India because of climate change **(Gosain *et al.,* 2006)**. Population across the globe is increasing and the resources of water are declining day by day. The condition is serious in the countries that are predominant in light-textured soil which has less water-retention capacity **(Berek, 2014; Dehkordi, 2016; Abrisham *et al.,* 2018; El-Asmar *et al.,* 2017)**. The soils in the arid as well as semi-arid zones around globe share common soil characteristics like truncated per cent of available organic matter and content of clay particles, water and less annual precipitation **(Yu *et al.,* 2011; Yu *et al.,* 2012; Xu *et al.,* 2018).**

As per **Begueria *et al.* (2010),** drought is a condition where extreme weather conditions prevail continuously and cause severe undesirable effects on the agriculture sector, groundwater and socioeconomic status of the nation. As per estimates, almost 70% of the freshwater will be used for agricultural purposes around the world with the population hike to 9 billion by 2050. Feeding this huge population will demand a 50% boost in crop productivity and amplify water requirements by 15% **(Oladosu *et al.,* 2019).** Drought in India is extremely persistent in nature and climatology of drought in India reveals that drought occurs once in five years in central and eastern Indian states like West Bengal, Madhya Pradesh, Bihar, Odisha, Bihar and Konkan regions. Drought occurs once in four years in southern Karnataka, Andhra Pradesh, eastern Uttar Pradesh and Vidarbha region **(Mishra & Singh, 2011).** Due to climate instability, food production losses have increased from a few incidents to hundreds in a decade as depicted in figure 2.1 **(IPCC, 2022).**

Several endeavours are being intended and established to perk up WUE in agriculture **(Kalhapure *et al.,* 2016).** The scarcity of water has forced to development of new approaches so that arid as well as semi-arid regions are not affected because of water scarcity. Water scarcity across the globe exists from one month to even a whole year as shown in fig 2.2. **(IPCC, 2022; Satriani *et al.,* 2018).** With the contrasting trend in present food demand and available water resources, food security has fallen into stern risk **(Kreye *et al.,* 2009).** Figure 2.3 represents the impact of climate change on the productivity of crop plants worldwide. Recently, employing modern irrigation practices has been vital to accomplishing the goal of global food security as well as producing good foods. However, intensive agriculture activities like indiscriminate use of fertilizers and tillage operations to achieve the aforementioned goal, causing depletion of soil fertility and increase soil erosion **(Kopittke *et al.,* 2019).**

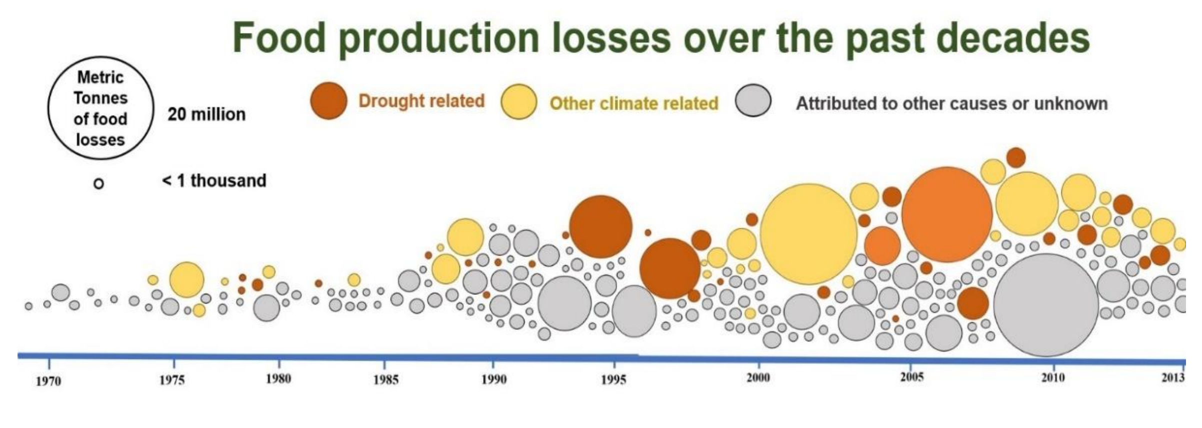


Fig. 2.1. Food production loss events over the past decades.

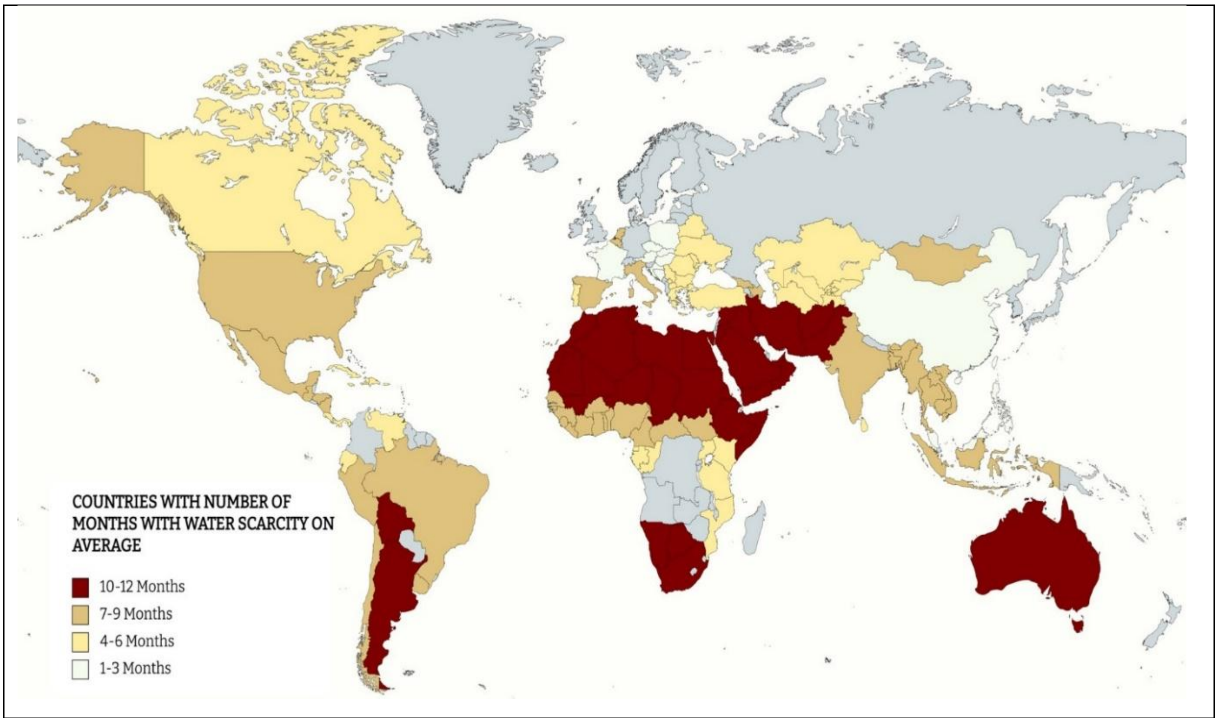


Fig. 2.2. Scenario of the months in a year in which water scarcity is > 100%.

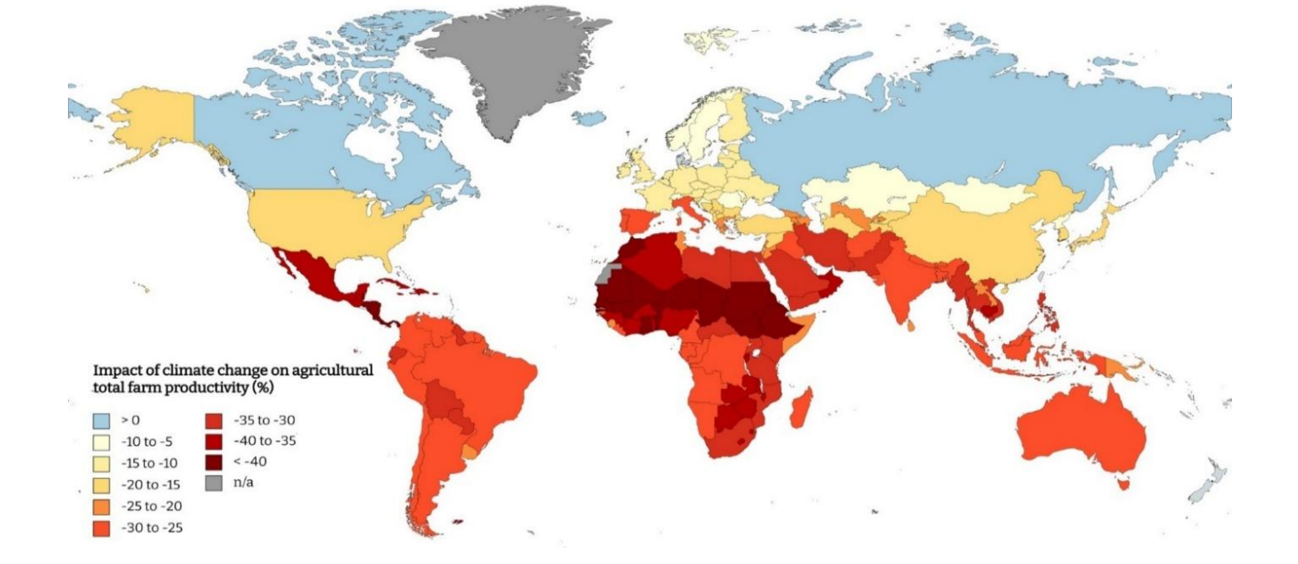


Fig. 2.3. Influence of climate change on agricultural farm productivity (%) (Friedlander, 2021).

WUE can be improved by improvising the soil water retention capacity (WRC) and further productivity of crops. **(Mi *et al.,* 2017).** Global food security is under severe threat with the increased production losses due to erratic weather conditions. Environmental disasters are leading to severe production losses in agriculture. Comparison of losses with the annual intake of kilocalories, iron, zinc and calcium uptake per year as per the estimates of **FAO (2021)** is depicted in fig 2.4. Under the water deficient conditions crops show responses like reduction of leaf area, closure of stomata, declined photosynthetic activity and reduced water potential. Due to the aforementioned reasons, there will be a dwindled yield as well as crop quality because of cramped growth of plants **(Pereira *et al.,* 2012).** Water is the most important factor that seems to be a major curbing one while accessing agriculture production **(Bai *et al.,* 2010).** Both irrigation as well as rainwater must be stowed for extended periods in the root zone which should be mandatory in water scare regions **(Yu *et al.,* 2011; Yu *et al.,* 2012).**

Water is a vital constituent for the subsistence and support of life on the planet. The total amount of water that exists entirely is not suitable for agriculture and human consumption. Only freshwater which constitutes 0.01% of total water in the world is apposite for the above-mentioned purposes. With the rise in the population and rapid urbanization, the freshwater demand has enhanced and is anticipated to aggravate further. To accomplish the needs of ever-increasing population and their food demand which poses a severe burden on agriculture to increase crop production, more land has to be brought under cultivation to reach the goal of global food security. The depletion of freshwater resources raises the alarm as irrigated agriculture is a major consumer. This has engrossed the attention globally and it is necessary to scout the techniques to enhance water productivity and mitigate consumption. Effective utilization of water resources by reducing water losses and safeguarding the proper vegetation for stable food production.

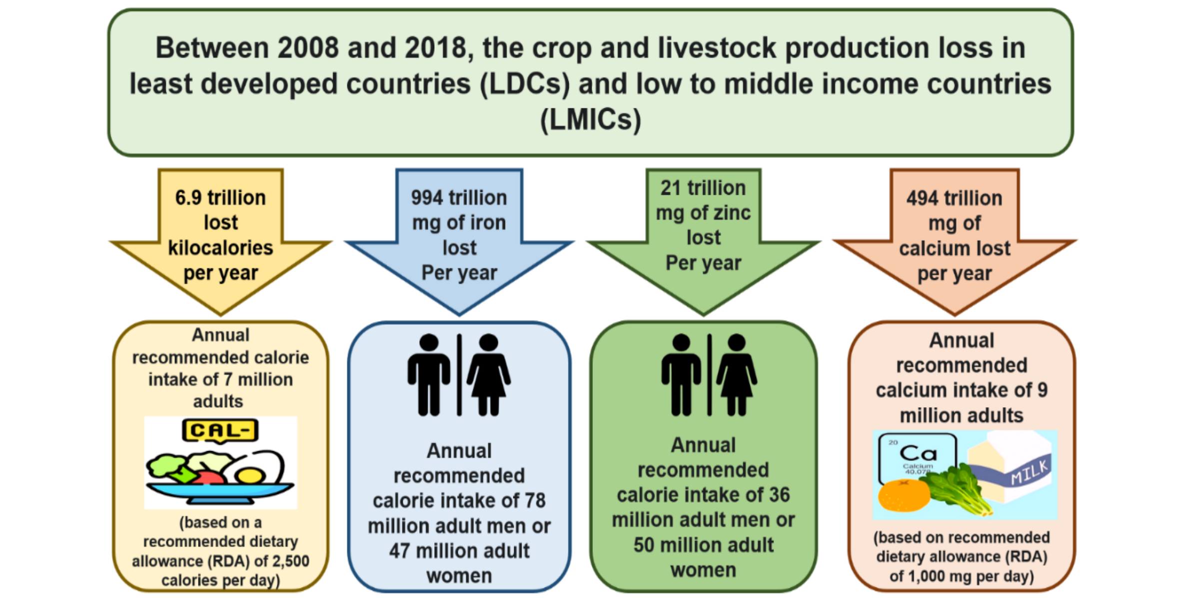


Fig. 2.4. Comparison of disaster-induced production losses with annual intake of kilo calories, iron, zinc and calcium uptake per year (FAO, 2021).

To fill the void between the production and consumption of food grains, more attention is required to hike the production of crops vertically and horizontally. New techniques must be employed to endow sufficient food quantity to feed the rising population across the globe. Implementation of substitute methods of micro-irrigation like drip and sprinkler systems, water harvesting measures, different practices like mulching, minimum tillage, reduced tillage, and ridge furrow method etc. are employed at present for the management of scarce water resources by the farmers. Earlier research has proved that the amendment of soils with polymers and minimum tillage operations reduces soil deprivation, thereby enhancing the WRC of soils in water scare zones **(Berek, 2014; Xu *et al.,* 2018).** The employment of super absorbent polymers (SAPs) in agriculture has gained prominence and explored to alleviate water stress by mitigation. Usage of super absorbent polymers (SAP) in sandy soils of arid zones enhances the water-holding capacity, which subsequently perks up the plant quantitatively and qualitatively **(Bakass *et al.,* 2012).** These hydrogels are the best for improving water availability and also enhance the WUE **(Liao *et al.,* 2016; Yu *et al.,* 2011; El-Asmar *et al.,* 2017).** Employment of new technology like hydrogel in agriculture is one such approach to improve WUE as well as crop productivity **(Abobatta, 2018).** The literature on the characteristics of the superabsorbent polymer-hydrogel and its impact on morphology, yield, water productivity, quality parameters and monetary advantage of various crops are considered under the following headings below.

2.2. Characteristics of superabsorbent polymer (SAP) – hydrogel

The super-absorbent polymer – hydrogel is a substance that has the ability to absorb and clasp a huge quantity of liquid matter based on its relative mass. These polymers absorb liquids, maybe water or any organic liquid, but their absorption capacity varies depending on the composition of the liquid **(IUPAC, 2004).** Three grades of SAPs are generally employed i.e., natural, semi-synthetic and artificial polymers. Hydrogel is a synthetic polymer, insoluble, and hydrophilic and absorbs enormous quantities of water when soil amended **(Schacht, 2004).** These SAPs can absorb water when available in the form of irrigation or rain and make it available to plants when required **(Akhter *et al.,* 2004; Kumar, 2020).** Primarily the hydrogel has the capability to absorb only 20 times more water than its weight. The accessibility of cross-linked polymer with high WRC has enhanced the absorption capacity to 400-2000 times its weight. When hydrogel comes in contact with water, it tends to swell into a gel form and retain a large quantity of water i.e., 400-1600 times the dry state or original weight mimics a sluggish water-releasing source in the soil and release the moisture when required by soil and plant as shown in figure 2.5 **(Suresh *et al.,* 2018; Ahmed, 2015).**

Fig. 2.5. Hydrogel in dry and swollen stage; diagrammatic representation of hydrogel in soil.

The cost-effective nature has rejuvenated the attention towards hydrogel employment in agriculture **(Dar & Ram, 2017). Kalhapure et al. (2016)** stated that hydrogel absorbs water, holds it with pressure and continuously discharges it to the plants based on the requirement. The structure, molecular weight and formation of hydrogel determine the amount of water that is to be absorbed **(Riad *et al.,* 2018).** The amendment reduces the irrigation frequency and expenses involved in the labour charge **(Dar *et al.,* 2017).** At present, hydrogel polymers are manufactured from moderately nullified, less cross-linked polyacrylic acid which tends to swell with water. These polyacrylic $(C_3H_5NO)_n$ formulations are dynamic long-chain polymers. Polyacrylamide formulations are artificial hydrogel which is manufactured as simple or cross-linked. The simple linked polyacrylamide is not suitable for agricultural purposes due to the dissolving nature in water. The cross-linked polymers are embedded into a cellulose-based polymer chain (**Kalhapure *et al.,* 2016). Ekabafe *et al.* 2011** resolved that hydrogel acts as a "miniature water reservoir". The osmotic pressure difference aids the plants in absorbing water and favours nutrient uptake. Thus, holding them firmly and delaying the nutrient dissolution. Eventually, enhanced nutrient mobilization, mineralization and absorption by the plants and helps to attain

Hydrogel is a super absorbent polymer (SAPs) that has an immense role in areas where the possibilities of irrigation are scarce. It can boost water availability during crop establishment by slowly releasing it under drought conditions **(Dehkordi, 2016).** When the soil has less available moisture and the plant root environment tends to dry, these SAP's gradually start releasing the absorbed and stored water up to 95% back into the soil. Despite being deswelled they recharge when the irrigation is given or when they make contact with water**.** The benefit of hydrogel is not just confined to the increase in water availability but it has some unique features of amplifying the properties of the soil mainly in the water scarcity zones **(Agaba *et al.,* 2010; Huettermann *et al.,* 2009; Xu *et al.,* 2018; Riad *et al.,* 2018 and Guo *et al.,* 2020).** The hydrogel as a soil conditioner can also amend different soil properties like WRC, infiltration rate, structure and density **(El-Hady & Abo-Sedera, 2006);** water holding capacity (WHC), soil permeability **(Heidari &Hosseini, 2024),** porosity and reduce soil compaction **(Ekebafe *et al.,* 2011).** It improves crop growth by hiking up the soil WHC thereby adjourning the PWP during drought-stress conditions**.** Several reports have recommended the positive impact of hydrogel on soil properties as well as crop growth **(Narjary *et al.,* 2012).** The irrigation requirement of plants has been reduced in the soil amended with the hydrogel which ultimately hikes WHC and reduces the water off **(Sharma, 2004).**

2.3. Evolution of hydrogels:

According to Lee, Kwon and Park, the term "*hydrogel*" was initially included in the article that was published in 1894 **(Shubhadarshi & Kukreja, 2020)**, but the current perspective was not described in that. In the year 1960, it was aimed to develop permanent contact with human tissues by using it. Hydrogels were the pioneer substance used for biomedical purposes in the mid-1970s. During the early 1960s, an American company "Union Carbide" introduced SAPs into the market. Commercial hydrogel manufacturing was initiated in the late 20th century with chemically transformed starch, cellulose and various other polymers viz., polyethylene oxide and polyvinyl alcohol. As time passed, the aims and goals have also expanded **(Buwalda *et al.,* 2014)**.

2.4. Classification of hydrogels

Hydrogels are cross-linked three-dimensional networked water-absorbent polymers. Hydrogels that are predominantly used in the agriculture sector have acrylic acid as the basic unit whereas polyacrylamides as the main unit **(Bai *et al.,* 2010).** Hydrogels now a day's made of starch **(Mahmoodi-babolan *et al.,* 2019)**; proteins **(Kong *et al.,* 2019)** and cellulose **(Mi *et al.,* 2017).** The main types of hydrogels, so far found suitable for the use in agriculture sector are depicted in table 2.1.

2.5. Scenario of hydrogel in India

The Division of Agricultural Chemicals, IARI (Indian Agricultural Research Institute), New Delhi, has engineered the cross-linked, semi-synthetic, cellulose-graft-anionic-polyacrylate super absorbent polymer named *"Pusa hydrogel"*. The main objective behind developing the polymer is to serve the water-scarce and drought-prone regions across the country. Initially, the exported hydrogels were performing disastrously in the Indian soils, so considering the limitations, ICAR has developed an indigenous hydrogel that proved to be efficient for India's environmental conditions. It has features such as towering fluid absorption when accompanied by fertilizers. Its capability to absorb at soaring temperatures and the impact of polymer matrix properties on crop growth and yield have engrossed the attention across the country. It was commercialized by Ministry of Science and Technology (MST), Government of India and National Research Development Corporation (NRDC) in alliance with a firm based in Chennai **(Anupama & Parmar, 2012).** In the year 2016, Chemtex specialty Ltd. commercially released the hydrogel with the brand name Alsta hydrogel; it was tested at the National Toxicology Center (NTC), Pune. It revealed that it has the potential to absorb water up to 400 times its weight and is certified as a non-toxic polymer. It can attune to all types of crops and soil conditions with reduced irrigation frequency. It has been reported to reduce soil moisture depletion because of less evaporation and has also been found to check nutrient leaching **(Anonymous, 2016).**

2.6. Applications of hydrogel in agriculture

2.6.1. Water and soil conservation in the agricultural land

Some of the drastic effects because of the paucity of moisture are diminishing chlorophyll content, early leaf shedding and lessening of grain, fruit and flower yield of plants. Hydrogel

Table. 2.1. Types of hydrogels based on the grafting technology suitable for agriculture.

	Mineral grafting type potassium polyacrylate	Starch grafting type potassium polyacrylate	None grafting potassium polyacrylate	None grafting type sodium polyacrylate
Effective period	Good (> 3years)	Bad (< one month)	Normal (1-6 months)	Bad (> one month)
Environmental impact	Normal (National degradation)	Very degradable (Biodegradable)	Normal (National degradation)	Bad (Cause of salinization of soil)
Salt-resistibility	Good	Normal	Bad	Bad
High-temperature performance	Good	Normal	Bad	Bad
Price	High	Normal	Low	Lowest
Picture				

application improves 50-70% water retention capacity. Water holding capacity (WHC) increased from 171% to 402% with the hydrogel application at 2g/kg. The increased WHC has been found to diminish the irrigation requirement of various crops **(Laxmi *et al.,* 2019).** The ascending tendency of water content in the soil with an increase in the prescribed amount of hydrogel dose in the soil proves the hike in WUE in water-scarce regions. It has an enormous influence on growth and yield which consecutively boosts farmer's economy **(Saxena *et al.,* 2021).** Hydrogel also persuades the characteristics of soil like permeability, structure, texture, density and water infiltration rate. Irrigation frequency decreases and runoff declines due to the aeration and microbial activity tend to be endorsed **(Neethu *et al.,* 2018).**

2.6.2. Improved fertilizer efficiency

Irrigation has many demerits and influences on the utilization of fertilizers, insecticides and herbicides. Many reports suggest that by hydrogel usage, synthetic fertilizer can be used effectively without any nutrient loss. It is found most appropriate for sustainable agriculture in arid and semi-arid zones. Furthermore, potassium polyacrylate is out of harm and non-hazardous so prevents contamination of agroecosystems **(Neethu *et al.,* 2018).** The hydrogel also enhances plant growth by catering the nutrients regularly **(Noppakundilograt *et al.,* 2015).** With high water absorbency, hydrogel provides a prosperous nutrient environment and releases the nutrients gradually. Hydrogels are gifted with this unique quality of slowly releasing the nutrients from the absorbed gel matrix and providing the nutrients long-lasting **(Rizwan *et al.,* 2021; El-Asmar *et al.,* 2017).** Nitrogen-based fertilizers which are available in the form of ammonium (NH_4^+) and nitrate (NO_3^-) persuade the N_2O release in the environment, which augment the climate change than the emissions of CO_2 **(Lenka *et al.,* 2017).** In recent times, many attempts have been carried out to trim down the nitrous oxide (NO_2) and methane (CH_4) emissions **(Malla *et al.,* 2005)**. Effectual preservation of the dissolved nutrients has been achieved by the application of these hydrogel polysaccharides, thereby diminishing the N leaching and extra nutrient necessity than recommended **(Bley *et al.,* 2017). Meurer *et al.* (2017)** have conducted research with biocompatible and pH-sensitive non-phytotoxic hydrochloride microgel encumbered with Fe_3^+ ions. Due to the effective delivery system to the surface of the leaf, the Fe_3^+ ions will bind sturdily on the surface of leaves; thereby boosting the leaf chlorophyll content.

2.6.3. Hydrogel as controlling agents of pests and diseases

Disease control in plants is the prime focus of food safety, particularly for shielding the nutrition reservoirs for characteristics of seed and plant embryos **(Pedrini *et al.,* 2017).** As per **Ismail *et al.* (2013)**, various insecticides and pesticides fall short of attaining anticipated targets due to their degradation, leaching and volatilization at the end which leads to the contamination of the environment along with animals, plants and human health problems **(Ravier *et al.,* 2005).** In the same way, fertilizer and herbicide application on the plants can directly affect crop production by excess use or spray drift. With the above-mentioned problems, guarded discharge of formulations made by hydrogel can be deployed. It can be effective for secure and efficient usage in agriculture which can lead to the shrunk toxicity, volatilization of pesticide, deterioration of soil and chemical leaching **(Chevillard *et al.,* 2012).**

2.6.4. Drought stress diminution

Drought is a major abiotic stress which affects plant development. These stressful conditions are successfully hindered, by the use of polymers like SAP or hydrogels. Production of reactive oxygen species (ROS) can be attained by drought stress conditions, which can lead to a harmful effect on carbohydrates, proteins, lipids and nucleic acids **(Dietz & Pfannschmidt, 2011)**. Production of oxygen free radicals takes place under drought stress conditions which sequentially enhance lipid peroxidation and oxidative stress in plants. Because of the aforementioned process, drastically affects the plant with evident indicators like stunted growth, decreased leaf area and foliar matrix damage **(Neethu *et al.,* 2018).** Plants have both enzymatic as well as non-enzymatic defence systems for searching and detoxifying ROS. Application of hydrogel under unfavourable conditions trims down the impact of drought stress by abridged oxygen radical formation. Similarly, the permanent wilting point (PWP) can be reduced, with an improved capacity to release nutrients as well as water in the rhizosphere and for long-lasting survival of plants during stressful situations**.**

2.7. Impact of hydrogel on the improvement of crop production

The influence of hydrogel on the augmentation of the growth, yield, soil quality, moisture and economics are described below:

As the hydrogel bears key characteristics of water absorption, retention and slow-release nature, the hydrogel manifests its significance in the mitigation of rhizosphere. Hydrogel absorbs and holds the water tightly, thus preventing the deep percolation of water, leaching of the nutrients in the soil and mitigating moisture loss in the soil due to evaporation and accessibility to the plant **(Mohawesh & Durner, 2019).** In addition, nutrient holding capability, fertilizer solubilizing as well as mobilization due to hydrogel impact the plant-water relations, thereby increasing nutrient uptake, effective translocation and utilization **(Radian *et al.,* 2022; Bairwa *et al.,* 2022).** Thus, it promotes cell division as well as elongation that eventually echoes in the superior plant growth attributes **(Sivapalan 2001; Kumar *et al.,* 2018).** The late vegetative and early reproductive stages of crops are the critical periods that are prone to stress development that impacts and defines the yield of a crop **(Jamwal *et al.,* 2023)**. Stress building at the aforementioned stages can result in underperformance of crops in terms of yield despite their superior growth during the vegetative stage **(Shivakumar *et al*., 2019; Rajavarthini & Kalyanasundaram, 2022)**. Photosynthates fail to translocate from source to sink due to the moisture and heat stress during the reproductive stage **(Roy *et al.,* 2019; Singh & Sandhu, 2020)**. Favourable hydro-thermal regime transfer and accretion enable the widening rate of proper grain filling and the astounding response of growth attributes conceivably resonates in straw yield as well **(Chikarango *et al.,* 2021)**. The hydrogel applied at higher dosages enhances the soil moisture and augments the plant growth, particularly at the early growth stages which are more prone to stress, disease and nutrient deficiency **(Kumar *et al.,* 2020; Akhter *et al.,* 2004; Kumar *et al.,* 2018);** a significant growth response can also be seen if the above-mentioned negative impacts are curbed with the hydrogel usage **(Anupama *et al.,* 2005).**

The influence of hydrogel was evident on the germination index where wheat was much more responsive followed by maize, radish, cucumber and okra **(Sasmal & Patra 2022)**. Its application aids the plants to overcome the dormancy with null phytotoxic consequences ultimately better germination and establishment in rice **(Rehman *et al.,* 2011)** and a pragmatic impact on the seedling survival as well as eucalyptus growth **(Viero *et al.,* 2000)**. The time for the next irrigation gets extended due to the water-holding properties of hydrogel which eventually leads to less water consumption and irrigations. Water consumption was reduced by 25 and 50% in summer and winter respectively in okra **(Cookson *et al.,* 2001)**; irrigation intervals were reduced in coffee **(Azevedo *et al.,* 2002)**. Decline in the irrigation demand in cucumber **(El-Hady *et al.,* 2006)**; extended the time for permanent wilting point (PWP) in *Cupressus arizonica* **(Koupai *et al.,* 2008)**. Hydrogel application has condensed the soil infiltration rate **(Vijayalakshmi *et al.,* 2013)**; no. of irrigations reduced in wheat **(Kalhapure *et al.,* 2016)**. It has also amended the physical condition of soil and the root density in turf grass **(Nektarios *et al.,* 2004)** by forming a superior root network that enables the improvement in nutrient uptake. **(Agaba *et al.,* 2011; Tyagi *et al.,* 2018)**.

The superior moisture regime in the rhizosphere enables the plant to produce phytohormones like Auxin and GA that help in ameliorating the growth **(Meena *et al.,* 2015; Dar and Ram, 2017; Barihi *et al.,* 2013)**. The phytohormone production, better nutrient translocation and photoassimilates due to improved plant-water relations promote growth and yield pragmatically **(Tripathi *et al.,* 2023).** The effectiveness of hydrogel will also vary based on the type of soil. The hydrogel application will be efficient mostly in the clay type of soil when compared to the sandy soil. The prior WHC of clay-type soil and the additional hydrogel application proved efficient **(Albalasmeh *et al.,* 2022).** Based on the material the hydrogel is derived from may also impact the efficiency. The hydrogel is made of different materials like cellulose and starch. The cellulose-based hydrogel has proved to be more effective in the enhancement of crop performance compared to other types of hydrogels. However, the hydrogel application was found superior to the control **(Sharma *et al.,* 2023; Jeevan *et al.,* 2023; Abd El-Naby *et al.,* 2024).** A similar improvement in the growth as well as yield of wheat was stated by **Cholavardhan *et al.,* (2023)** and in maize by **Rasadaree *et al.* (2021).** With a shelf life of more than a year, these hydrogels can be performed without any negative effects of being old in the second season. The hydrogels are proven to be efficient and similar in their effect on different cropping seasons **(Rajanna *et al.,* 2022).** The hydrogel with the nutrient-holding capacity aids in the prevention of nutrient losses and increases nutrient accessibility. They are efficiently utilized by the plant during the cropping season and the leftover nutrients that are present in the soil are tightly held by the hydrogel polymer that can utilized by the crop in the next season (which is sure to be lost into the atmosphere in the form of nutrient losses if no hydrogel is applied) **(Manish *et al.,* 2022; Malaa *et al.,* 2023; Rasadaree *et al.,* 2021; Patel *et al.,* 2023)**. Similarly, the hydrogel holds the water due to which the requirement for irrigation is reduced and helps in water conservation without facing any kind of reduction in the plant performance **(Gilbert *et al.,* 2014)**.

There are several studies conducted on the diversity of crops that show the progressive influence of hydrogel application on growth attributes like stem diameter, leaf number, area, plant height and water content of maize **(Islam *et al.,* 2011; Sasmal and Patra, 2022)**. A positive impact on plant height, leaf area index, tiller number, crop and relative growth rate of wheat **(Kumar *et al*., 2019; Roy *et al.,* 2019)**. Hydrogel amendment has augmented the plant height of soybean **(Sivapalan, 2001)**; on the branches count per plant in peanut **(Langaroodi *et al.,* 2013)**. Similar enhancement in growth attributes in capsicum **(Hafiz-Afham *et al.,* 2023)**; on plant height, leaf and tiller number per clump in ginger **(Kumar *et al.,* 2018)** was reported. Similarly, an improvement was reported in the grain yield of soybean by 20% **(Yazdani *et al.,* 2007)**; on yield parameters like spike and grain number/plant, test weight, spikes/m^2, grain, stover and biological yield of wheat **(Mahla & Wanjari 2017; Grabinski & Wyzinska 2018; Kumar *et al.,* 2019; Roy *et al.,* 2019)**; on cob length, cob diameter of sweet corn **(Radian *et al.,* 2022)** and on grain count per cob and grain yield of maize **(Shivakumar *et al.,* 2019)**.

2.8. Impact of irrigation strategies on the economics

Hydrogel application reduces irrigation costs by lowering water consumption by 30-50%, directly cutting expenses on electricity, labour and water charges. Farmers using electric pumps or diesel engines for irrigation benefit from reduced power bills and fuel costs, leading to significant financial savings (**Kumar *et al.,* 2017**). Additionally, fewer irrigation cycles require less labour for water management ultimately reducing the labour cost involved. By retaining water in the root zone for extended periods, hydrogels prevent water runoff and deep percolation losses and maximize water-use efficiency **(Sasmal and Patra, 2022; Chikarango *et al.,* 2021).** This reduces the need for frequent re-irrigation, helping farmers save money on irrigation maintenance. The initial investment in hydrogel application can be recovered through cost savings in water, electricity and fertilizers making it a financially viable option (**Radian *et al.,* 2022**). In drought-prone and water-scarce regions, hydrogel application allows farmers to continue crop production with minimal irrigation resources and ensure a stable income (**Jamwal *et al.,* 2023**). This also enables multi-cropping or off-season cultivation and increases overall farm revenue. Crops grown with hydrogel exhibit better growth, higher yield and improved quality (**Kumar *et al.,* 2020**), leading to better market prices and increased profits (**Salem *et al.,* 2023**). Overall, hydrogel application results in 20-40% higher net profitability by reducing irrigation costs, labour expenses and input wastage, making it an economically beneficial solution for sustainable farming (**Shivakumar *et al.,* 2019**).

2.9. Biodegradability of hydrogel

Hydrogel is very sensitive to UV rays, and it gets degraded to oligomers. Aerobic and anaerobic microbial activity in the soil makes the polyacrylate more vulnerable to degradation. The polymer gets degraded at the rate of 10-15% per year and converted to carbon dioxide (CO_2), nitrogen compounds and water. These hydrogel polymers cannot be absorbed by the plant tissue as the molecules of the hydrogel are too capacious and have zero bioaccumulation latency **(Neethu *et al.,* 2018)**.

2.9. Crop geometric strategies

2.9.1. Characteristics of crop geometric strategies

In the current study, the crop geometric strategies comprise the crop geometry and usage of the seed capsule. The crop geometry is a key aspect that defines growth and yield of the crop. With depleting resources in the agriculture sector, effective utilization of them is of prime importance. Out of various techniques, the crop geometry is an effective one as it allows the plants to effectively utilize resources like sunlight, water and nutrients from soil that can impact the yield of the crop. The wider planting permits effective resource utilization by avoiding competition. Competition is the main aspect that affects the crop negatively, particularly at the early growth stages. The closer plant spacing increases the competition among the plants and also the weeds. The wider spacing allows a better intercultural operation than the closer spacing. In the maize, the paired row spacing is gaining prominence which is different from the conventional spacing. In paired row spacing the two rows are brought nearer to make a pair and further increase the distance between the two pairs by maintaining the same plant-plant spacing. The paired row spacing is devoid of any plant population loss when compared to the conventional spacing. Normally paired row spacing is adopted when a farmer is planning for intercropping to best utilize the inter-pair spacing. However, in the current study, our objective was to evaluate the sole impact of various crop geometries on performance of spring maize. Because of this reason, intercropping was not adopted.

Capsule technology is a new technology that is engrossing attention nowadays, in which empty gelatin capsules are encapsulated with biological components for target-based delivery to crops. In India, capsule technology was initially developed, tested as well as commercialized by the ICAR- Indian Institute of Spices Research (IISR), Kozhikode, Kerala **(International Pepper Community, 2024).** They have encapsulated the microorganisms and plant-growth regulators for the smart delivery to the crops. This technique can be used for delivering micro-organisms, viz., nitrogen fixers, plant growth-promoting rhizobacteria (PGPR), nutrient solubilizers/mobilizers, Trichoderma etc **(ICAR, 2024).** The seed capsule in the present study is a modified version of the bio capsules in which seed of the crop, biofertilizers, humic acid and neem powder are encapsulated in the gelatine capsule. Every ingredient that is encapsulated has its role in crop improvement. The seed capsules are easily soluble and take less than a minute to dissolve when irrigation is given. After the capsule is dissolved the ingredients create a microenvironment in the rhizosphere and promote germination as well as protect the seedling in the early growth stages from soil-borne pathogens.

In the contemporary period, the utilization of synthetic fertilizers has enormously enhanced and farmers are attracted to them due to their fast-releasing nature and relatively inexpensive than organic fertilizers. With the green revolution in the 1960s, synthetic fertilizers have shown an impact in improving crop productivity and resulted in dependency on them considering the rise in the population as well as their food demand **(Shubhadarshi & Kukreja, 2020).** The haphazard use of synthetic fertilizers has drastically affected the soil properties and further declined soil fertility. The key drawbacks of these fertilizers are residual effect and toxicity which change soil health (**Ghany *et al.,* 2013).** These fertilizers in high doses impact the soil flora and fauna. The leaching and runoff of nutrients cause environmental contamination and pollution (**Mishra *et al.,* 2013).** To manage the aforementioned drawbacks the integrated nutrient management approach is one of the effective methods in which biofertilizers can be a key component of INM practices. Biofertilizers help plants utilise nutrients more efficiently and condense the need for chemical inputs. Humic acid is a natural organic compound that plays a complementary role in improving soil health and encouraging plant growth. Humic acid enhances the germination, nutrient absorption, permeability of plant membranes, efficiency of the root system, root growth and overall performance of the plants **(Deshmukh *et al.,* 2023).** Neem powder is an organic fertilizer that improves soil properties, protects plants from disease and enhances crop productivity. It is compatible with soil microbes and improves rhizosphere microflora. Neem powder ensures fertility as well as protects plant roots from various soil-borne pathogens, particularly at the early crop growth stages **(Adusei & Azupio, 2022).**

2.9.2. Crop geometry

Crop geometry is the prearrangement of the plants in the different rows and columns in a given piece of area for the efficient exploitation of natural resources like water, light and nutrients etc for attaining better plant performance in terms of growth, productivity and quality of the crop **(Thakur *et al.,* 2020).** The optimal plant spacing aids in enhanced growth as well as development of the crop without hindering the performance of the neighbouring plants. Maintaining the optimal crop geometry assists in the uniform distribution of solar radiation and ensures that every plant receives sufficient solar radiation for the production of energy **(Mohan *et al.,* 2021)**. Competition is a severe problem that impacts the growth as well as the productivity of the crop. The narrow spacing increases the competition between the plants in a crop and the weed infestation is an additional competition for the resources that will impact the crop growth and production. The weeds and crops compete for similar resources like nutrients, light, moisture, space and growth elements **(Sangeeta *et al.,* 2023)**. It distresses the yield by impacting the light interception, moisture extraction and rooting pattern and eventually stress development **(Lal *et al.,* 2022).** Better sunlight interception aids in superior photosynthetic activity **(Uphoff *et al.,* 2011)** and when competition for moisture is curbed, it helps in good plant-water relations and ultimately superior photoassimilates translocation from source to sink **(Waghmare *et al.,* 2018)**.

The incidence of insects and pests can be effectively abridged by sustaining optimal plant spacing **(Aliveni *et al.,* 2020).** Improved air circulation enhances plant growth by preventing excess moisture buildup on the leaves and also helps in keeping the foliage dry as the excess moisture can increase the risk of diseases and pests. **(Nand, 2015)**. The range of competition between plants for moisture, light and nutrients plays a crucial role in nutrient absorption/uptake by plants. With narrow or close spacing, the competition increases and eventually, that will lead to poor plant water relations, nutrient availability and photosynthetic activity; subsequently deprived plant nutrient uptake **(Ghosh *et al.,* 2009)**. The usage of chemical fertilizers and wider plant spacing facilitates the proper establishment of crop canopy because the resource-conservative approach with the wider spacing enables the efficient exploitation of chemical fertilizers by preventing nutrient losses **(Ibrahim *et al.,* 2022)** and improving the yield-contributing attributes development **(Qodliyati *et al.,* 2018)** eventually yield **(Seran & Brintha, 2009)**. The paired-row spacing has been gaining prominence because this type of spacing pattern has initially given productive results in enhancing growth and productivity in maize **(Kumar *et al.,* 2017)** and other crops. The competition for resources exists only between the plants in the row that promotes growth and yield in cash crops like sugarcane **(Srilathavani *et al.,* 2020)**; cotton **(Parmar *et al.,* 2023)** in leguminous crops like chickpea **(Khan *et al.,* 2010)** and pigeon pea **(Rani *et al.,* 2020)**.

2.9.3. Seed capsule

The seed capsule is prepared by filling a seed, biofertilizers, humic acid and neem powder in the empty gelatin capsule.

2.9.3.1. Biofertilizers

Currently, the rapid increase in the population is seriously threatening global food security, with the present global population (7 billion) anticipated to rise to 10 billion in the future **(Kumar *et al.,* 2018; Linares *et al.,* 2020). According to FAO (2022),** 8% of the population on the planet will experience famishment by 2030. Additionally, worldwide agriculture is facing a serious threat of climate change and negative environmental impacts. To accomplish the necessities of the accelerating population, already burdened global agricultural production has to increase drastically **(Hasler *et al.,* 2017)** to ensure global food security sustainable crop production is of paramount importance without harming the environment **(Panwar & Vijayaluxmi, 2005).** In the mid-1960s, global nations focused mainly on self-sufficiency to ensure food security, leading to the green revolution. The revolution has left some harsh impacts like diminished nutrient use efficiency, adverse soil nutrient balance and diminutive crop response ratio etc. The negative effects are principally due to the indiscriminate use of synthetic fertilizers, plant protection chemicals like insecticides, pesticides and herbicides, improved seed varieties and secured irrigation **(Sreethu *et al.,* 2023).**

The application of these fertilizers has enhanced crop production with nutrients readily available to plants to attain global food security. The bio-physio-chemical properties of soil were diminished by the farmer's complete dependence on the over-exploitation of agrochemicals **(Dar and Bhat, 2020)**. The excessive application of these chemicals has increased pollution and impaired soil flora and fauna, fertility, organic matter (OM) and augmented pollution **(Dar *et al.,* 2016; Dinesh *et al.,* 2010)** eventually poor crop productivity **(Singh *et al.,* 2020; Dervash *et al.,* 2020; Musthaq *et al.,* 2020).** Out of applied fertilizers, only a tiny part is used by the plants while the rest of the fertilizers are lost by leaching, surface runoff etc which increases the demand for more fertilizer by the plant and further the increment in the cultivation cost and environmental contamination **(Fasusi *et al.,* 2021)**. As per the estimation of the **FAO (2023)**, the use of nitrogen, phosphatic and potassic fertilizers has increased by 46.47%, 53.11% and 25% respectively in 2020 compared to 2000. According to the estimates of **Sapkota *et al.* 2018,** the usage of N fertilizers is solely responsible for 60% of N pollution. The detrimental impacts of these chemical fertilizers include soil acidification, increased disease incidence, weakening of the plant roots, eutrophication and groundwater contamination **(Wang *et al.,* 2015; Youssef & Eissa, 2014)**. The groundwater contamination due to the leaching of N fertilizers causes "*blue baby syndrome*" which is also referred as "*acquired methemoglobinemia*". Dreadful effects of chemicals on human health aren't just confined to the current generations but can impact future generations **(Kumar *et al.,* 2018)**.

Soil is an active living body and comprises numerous various living organisms. The main objective of natural agricultural practices is to improve biodiversity, biological cycles and soil microbial activity to achieve food security goals in a sustainable manner **(Wahane *et al.,* 2020)**. The rhizosphere in the soil is normally referred to as the reservoir of microorganisms, as the presence of the microbes in the vicinity of the root is high compared to the non-rhizosphere soil. This drastic difference in the microbial population in the rhizosphere is because of root exudates from the plant roots **(Etesami & Maheshwari, 2018).** The microbial consortium increases nutrient absorption by the plants and promotes growth. Possibly with the fluctuating climatic conditions in the near future, the biofertilizer consortium can be an effective resolution to enhance the plant performance, hasten the yield productivity and stress tolerance to the erratic weather conditions **(Anli *et al.,* 2020)**. Biostimulants are naturally occurring compounds or microorganisms that are provided to plants to enhance their nutritional efficiency, abiotic stress tolerance, and qualitative characteristics, irrespective of the amount of nutrients in the crop **(Nogot *et al.,* 2022)**. Soil health as well as crop production are harshly impacted by various relations between soil, plant and microbes **(Harman *et al.,* 2021)**. Plant microbial relations positively affect plant endurance, crop performance, productivity and nutrient availability to the plants for sustainable agriculture **(Vishwakarma *et al.,* 2020)**. Biofertilizer application improves the microbial population which drastically impacts nutrient accessibility and organic matter decomposition **(Chaudhary *et al.,* 2021)**.

Biofertilizers comprise specific microorganisms i.e., microbial inoculant consortium, organic compounds and perished plant tissues that are acquired from the rhizosphere and roots **(Sahoo *et al.,* 2013)**. Biofertilizers are naturally occurring fertilisers based on biological materials, such as plants, animals, or dormant microbial cells **(Abbey *et al.,* 2019; Lee *et al.,* 2018).** They are eco-friendly and are living cells of various types of microorganisms that can enhance bioavailability as well as bio-accessibility by mobilizing nutritionally vital elements for plants from the non-usable form to the usable form **(Thejesh *et al.,* 2020).** They enhance the soil quality and increase crop production significantly helping farmers at extremely cheap input costs has garnered attention **(Kumudha, 2005; Kumudha & Gomathinayagam, 2007).** As per the reports of **Kawalekar, 2013; Stewart & Roberts, 2012, a** 40% increase in the growth as well as yield of plants was recorded with the application of biofertilizers.

Biofertilizer consortium is the combination of more than one living/latent cell of microorganisms that increases the nutrient fixing, solubilization and mobilization, thereby restoring the nutrient concentration in the rhizosphere and are more readily assimilated by the plants **(Mishra *et al.,* 2012; Malusa & Vassilev, 2014)**. The benefits of microbial consortium application include their cost-effective nature, improved nutrient availability, soil fertility, plant protection, stress tolerance, sustainable agricultural production, encouraged phytohormone production, environmentally friendly and constant application significantly increases the soil fertility on the long-term basis **(Chaudhary *et al.,* 2022)**. In the global market based on the source and raw material, biofertilizers are categorized into two types of biofertilizers *i.e.,* organic residue-based biofertilizers (green manure, crop residues, farmyard manure and treated sewage sludge) and microorganism-based biofertilizers (comprise of helpful microbes like bacteria, fungi and algae). Application of the microbial consortium in the form of seed treatment, soil amendment, root dipping, microbial encapsulation and fertigation. They colonize the rhizosphere and improve the plant performance by enhancing the accessibility of nutrients to the plant **(Daniel *et al.,* 2022)**. In the current study, the biofertilizers are applied through microbial encapsulation in which the microbial consortium is encapsulated in the gelatin capsule. The various methods of biofertilizer application are depicted in fig 2.6.

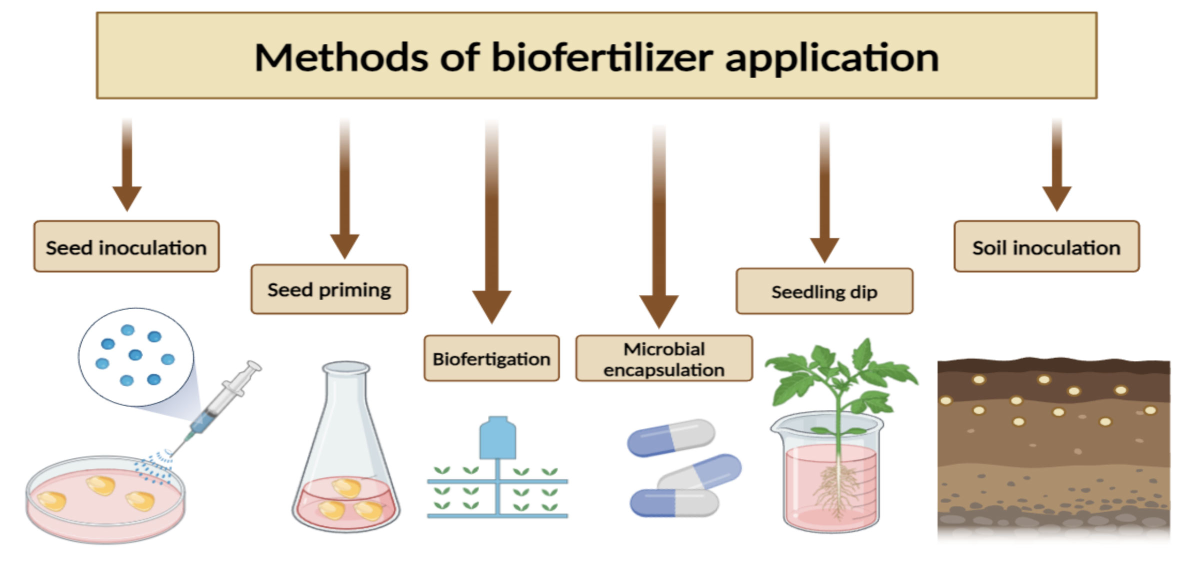


Fig. 2.6. Methods of biofertilizer application.

2.9.3.2. Types of biofertilizers used in the current study

1. **Nitrogen-fixing biofertilizers**

Nitrogen is a dynamic nutrient which restricts plant growth if deficient **(Gupta *et al.*, 2012)**. It enhances the shoot growth and increases the grain size. It is the key constituent of chlorophyll. If the plant is deficient in the N the plant colour will be light green, while if sufficient N is available then the plant appears deep green **(Sandhu *et al.*, 2021)**. Despite 79%, of N being present in the atmosphere, most plants cannot exploit it from the air. To make it accessible for the plant certain groups of bacteria are essential for the N fixation. **(Reed *et al.*, 2011)**. These microorganisms first convert the N_2 into a soluble non-toxic form of ammonia (NH_3) **(Abbey *et al.*, 2019)**. Then the NH_3 is converted into NO_2^- and NO_3^- forms with the help of ammonia-oxidising bacteria and nitrifying bacteria respectively. With the process of denitrification, the unused NO_3^- is then transformed into atmospheric N in the deeper soil horizons that escape in the form of N_2 gas into the atmosphere. **(Roy *et al.*, 2020; Mahanthy *et al.*, 2016)**. The volatilization of unused N in soil into the atmosphere as pollutants like N oxides and methane harm the ecosystem by diminishing the ozone layer (O_3), soil acidification and eutrophication **(Thangarajan *et al.*, 2018; Tantray *et al.*, 2022)**. The nitrogen fixation yields about 350 kg/ha N in a year and fulfils about 25% of the N requirement of the plants during the cropping season and can enhance crop production by 20-50% **(Sharma *et al.*, 2020)**.

Azotobacter sp. aid in the N fixation and boost the growth and productivity of maize, rice and various agro-forestry plants **(Azeem *et al.*, 2022; Etesami *et al.*, 2014)**. The *Azotobacter chroococcum* inoculation has amplified the growth as well as chlorophyll levels in the maize **(Jain *et al.*, 2021)**. The application of *Pseudomonas protegens* in the N-deficient soils has amplified growth and productivity **(Jing *et al.,* 2020)**. **Mondal *et al.,* (2020)** concluded that by secreting chitinase enzyme the *Rhizobium meliloti* aided in N-fixation and amplified the groundnut yield; interaction between alfalfa-rhizobium stimulated N – fixation and encouraged phytohormone production, eventually growth attributes **(Fang *et al.,* 2020)**. Azotobacter is an extensively studied bacterium due to its free-living, phototropic and non-symbiotic nature. The *Azotobacter chroococcum* can fix one gram of N per 100 grams of C source provided in-vitro **(Mukherjee *et al.,* 2022)**. Azotobacter is a nitrogen-fixing bacterium that thrives in aerobic soil conditions and helps improve soil fertility. It fixes 10–50 kg of nitrogen per hectare per year, making atmospheric nitrogen available to plants **(Yasuda *et al.,* 2022; Sreethu *et al.* 2024)**. Azotobacter is reported to produce plant-growth-promoting hormones like gibberellic acid (GA), indole acetic acid (IAA), naphthalene acetic acid (NAA) and vitamin-B complex **(Seenivasagan & Babalola, 2021; Pereyra & Creus, 2017)** that hinder the root pathogens thereby endorsing the nutrient uptake, root growth **(Kumar *et al.,* 2020)** enhanced soil fertility **(Mahanty *et al.,* 2016; Sumbul *et al.,* 2020)**. Acetobacter is a free-living nitrogen-fixing bacterium that colonizes plant roots, stems, and leaves. It fixes 20–200 kg of N per hectare per year, reducing the need for synthetic fertilizers (**Fang *et al.,* 2020**). Acetobacter enhances nutrient uptake, root growth, and chlorophyll content, leading to higher crop yields (**Soumare *et al.,* 2020**). It also produces growth-promoting hormones like auxins and gibberellins, improving plant health (**Gohil *et al.,* 2022**). Along with N fixation, it improves soil fertility by increasing organic matter and phosphorus availability, making it an essential component of sustainable agriculture **(Mahanty *et al.,* 2016; Sumbul *et al.,* 2020)**.

2. Phosphorous-solubilizing biofertilizers (PSB)

Phosphorous (P) is the 2^{nd} most essential macronutrient by plants after N, which limits plant growth and development **(Bechtaouci *et al.,* 2021; Bamagoos *et al.,* 2021)** as it is intricate in various metabolic activities like ATP and amino acid synthesis **(Tian *et al.,* 2020)**. In the environment, the sedimentary rocks and rock phosphate are the principal reservoirs of P. The PSB convert the inaccessible form to the accessible form (orthophosphate forms) by solubilizing the inorganic P as well as mineralizing the organic P **(Barin *et al.,* 2020; Tian *et al.,* 2021)**. The PSB produces the organic acids that drop the soil pH, which leads to the phosphate compound dissolution and enhances the accessibility of soil P **(Mahanty *et al.,* 2016)**. The inoculation of *Rhizobium leguminosarum* and *Pseudomonas moraviensis* has amplified the growth as well as yield of wheat by the increased production of IAA and P solubilization **(Fahsi *et al.,* 2021; Igiehon *et al.,* 2019)**. **Zhang et al. (2019)** stated an enhancement in the safflower yield and protection from the salinity stress with the inoculation of Bacillus subtilis. Arbuscular fungi application has enhanced the availability of P and stress reduction in the *Helianthus tuberosus* L. **(Nacoon *et al.,* 2020)**. The PSB application as NanoPhos augmented the maize yield by enhancing the microbial population and soil enzyme production **(Chaudhary *et al.,* 2021)**.

3. Potassium solubilizing biofertilizers (KSB)

Potassium (K) is the 3rd main macronutrient required for crops after N and P. Potassium is primarily involved in stomatal regulation, protein synthesis, stress resistance development and nutrient uptake **(Santosh *et al.,* 2022)**. Potassium exists in the mineral form, which makes it unavailable to the plants. The inoculation of the KSB aids in the conversion of the inaccessible form of K to the accessible form of K and increases microbial diversity, organic matter decomposition and overall nutrient cycling. **(Dong *et al.,* 2019; Parmar & Sindhu, 2013; Masood and Bano, 2016).** Based on the soil composition, the K exists in various forms i.e., available non-available and water-soluble forms **(Basak *et al.,* 2022)**. Potassium normally exists as immobilized silicate mineral forms like feldspar, biotite, orthoclase and illite etc. Similar to the PSB, the KSB produces organic acids (acidification), enzymes and chelating compounds that solubilize the K by disintegrating the silicates and eliminating the metal ions **(Varga *et al.,* 2020)**. **Ali *et al.* 2021** reported that Bacillus cereus has shown an impact on potato growth and yield parameters by enhancing the K solubilization by producing phytohormones like auxins and gibberellins, enhancing plant development. According to **Chen *et al.* (2022)** by the expression of K-solubilizing genes, the *Bacillus aryabhattai* has improved the K-solubilization, stress resistance and plant growth. **Dal *et al.,* (2020)** stated an upsurge in the activity of soil enzymes as well as growth in wheat with the combined application of KSB like *Rhizophagus irregularis* and *A. vinelandii.*

2.9.3.3. Mechanism of action of microbes in the rhizosphere

The excessive usage of synthetic fertilizers has depreciated the microbial flora and fauna in the soil. A positive relationship between plants and advantageous microbes has been a promising approach to improve crop production. These biofertilizers mediate the performance of plants through direct or indirect mechanisms as depicted in fig 2.8. The direct mechanism includes increased nutrient availability and plant growth by regulating plant hormone production **(Santoyo *et al.,* 2021)**. The different molecules like siderophores intracellularly produce aminocyclopropane-1-carboxylate deaminase or extracellularly near the root zone. Eventually decreases the ethylene levels and osmotic stress in the plants and eventually the growth and development **(Zahir *et al.,* 2008; Nadeem *et al.,*2007)**. Whereas indirect mechanisms comprise the usage of biocontrol agents to condense repressive impact of plant pathogens and abiotic stress amelioration **(Glick, 2012; Ahemad & Kibret, 2014; Bargaz *et al.*, 2018)**. Usually, biofertilizers colonise the root surface, increasing the surface area that can facilitate nutrient absorption and consequently crop production and output. They promote root hair development, which improves the water uptake capacity of plants. Eventually, this provides the plant resistance and defence against infections, biotic and abiotic conditions like temperature drought and salt stress **(Rajkumar *et al.*, 2010)**. Plant hormone productions like GA and IAA enhance the physiological and developmental processes rapidly and long-term plant response in plants **(Kasahara, 2016)**. Plants normally live in extremely intrinsic conditions and are typically experiencing abiotic as well as biotic stress that reduces the yield by 50% and tends to increase because of the erratic weather conditions **(Ramegowda & Senthil, 2015)** with the wide range of defence mechanisms to combat stress. Ethylene production is a phytohormone that curbs the response to stress. The inoculation of *Bacillus aryabhattai* has stimulated an enduring defence retaliation to infections, with the help of ethylene or salicylic acid pathways **(Portieles *et al.*, 2021).**

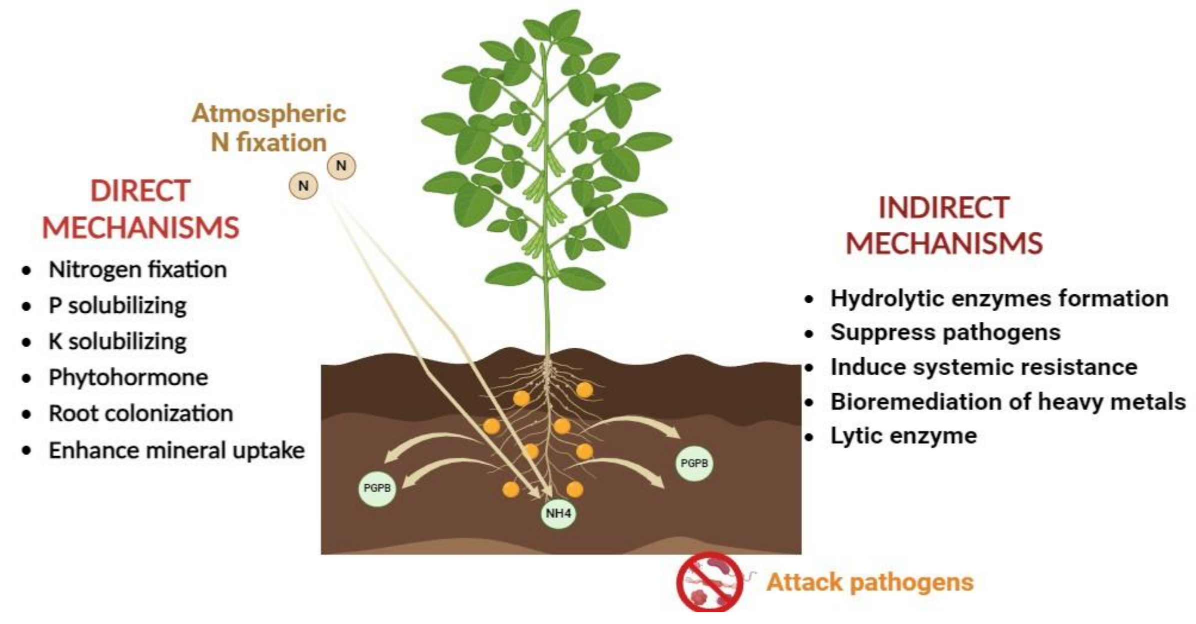


Fig. 2.7. Beneficial aspects of plant growth-promoting bacteria.

2.9.3.4. Functions of biofertilizers in the management of abiotic and biotic stress

The plants are frequently exposed to severe biotic as well as abiotic stress due to various factors. The biofertilizers have shown some impact in curbing the stress on the plant and efficient management. The functions of biofertilizers in the stress management of cereals are described in table 2.4. The unsystematic usage of chemicals has created a substantial menace to the ecosystem with the increased disease outbreaks in many crops **(Akanmu *et al.*, 2021)**. The excessive usage has deteriorated the soil, leading to crop failure and losses. The efficient and environmentally friendly approach of biofertilizer application has been promising in improving crop production. The usage of microbes like *Streptomyces, Bacillus, Pantoea* and *Pseudomonas* species has been efficient in biological control of pests by destructing the pathogen **(Chaudhary *et al.,* 2021; Kohl *et al.,* 2019)**. The endosymbionts do not just colonize plant tissues but protect the plant during the entire crop cycle **(Lahlali *et al.,* 2022)**.

Bacillus thuringiensis (Bt) produces endotoxins and is a gene source for transgenic plants which are resistant to insects and is an efficient biopesticide **(Sujayanand *et al.,* 2021)**. Secondary metabolites are the key components as part of the defence mechanism by secreting metabolites and protection against pests, diseases and pathogens **(Divekar *et al.,* 2022).** The volatile compounds released by fungal endophyte *Phomopsis* species have hindered fungi like *Deuteromycetes* and *Ascomycetes* **(Hummadi *et al.,* 2022)**. **Hennessy *et al.* (2022)** concluded that *Epichloe festucae* has defended against insects by colonising the forage grasses. **Xia *et al.* (2022)** reported that few endophytes control stress management through SAR (Systemic acquired resistance) facilitated by salicylic acid. Systemic acquired resistance aids in long-term stress reduction and wide-ranging efficacy against different pathogens. In recent years, the incidence of abiotic stresses like heat, salinity, drought and waterlogging in agriculture has increased drastically mainly because of climate change **(He *et al.,* 2018)** and the yield losses account for 50-80%, because of the abiotic stresses **(dos Santos *et al.,* 2022)**. The photosynthetic rate and yield of Phaseolus vulgaris have enhanced under water stress conditions with the application of *Bacillus amyloliquefaciens* and *Glomus mosseae* by abiding the drought stress **(Al-Amri, 2021)**.

The use of biofertilizers has countered the fatal properties of salinity by enhancing soil physicochemical properties and ultimately crop productivity **(Jimenez-Jimenez *et al.,* 2019)**. *Azospirillum* has enhanced the salinity resistance in maize by increasing the antioxidant enzyme and glycine production **(Checchio *et al.,* 2021)**. The inoculation of PGPR has enhanced the growth of lettuce by increasing the IAA and antioxidant production to offer defence under salt-stress conditions **(Fortt *et al.,* 2022)**. Inoculation of *Burkholderia* and *Rhodococcus* has protected the *Atractylodes lancea* from heat stress by elevating the root-associated microorganisms and eventually improving growth and development **(Wang *et al.,* 2022)**. The inoculation of *Serratia marcescens* under lead and cadmium toxicity conditions has amplified spinach growth by producing polyamines **(Wang *et al.,* 2022)**. Cadmium and lead toxicity was mitigated by the inoculation of Citrobacter and Enterobacter in the wheat and improved the growth **(Ajmal *et al.,* 2022)**. The rhizobium inoculation endorses nutrient cycling in the metal-contaminated soil by enhancing the soil enzymatic activity, N and P accessibility **(Duan *et al.,* 2022)**.

2.9.3.5. Impact of biofertilizers on the improvement of crop production

The soil amendment of biofertilizers plays an essential role in amplifying growth, yield contributing attributes and eventually the yield. They enhance nutrient accessibility and sustainably ameliorate soil and plant health. The inoculation of *Azolla* in the rice efficiently enhances the N availability due to its rapid decomposition in the soil **(Yadav *et al.,* 2019)**. According to **Thamatam & Mehera, (2022)**, the efficacy of biofertilizers on crop production was more effective with the combined application of Azotobacter and Azospirillum than with the sole application. It may be due to the increased nutrient fixation that has enriched the rhizosphere with the nutrients and eventually, it has resonated in the enhancement of the growth and yield of the sweet corn. Organic manures are key factor that affects the soil condition as well as the soil microbial flora and fauna **(Saini *et al.,* 2004)**. They are made of natural materials like animal manure and compost etc. The organic manures include vermicompost, humic acid, neem cake powder, compost, poultry manure, farm yard manure, green manure etc. The organic manures normally help to provide a suitable environment for microbial growth, when inoculated and incubated for a fortnight, it helps to enhance the microbial population **(Adhikari *et al.,* 2005; Thejesh *et al.,* 2020)**.

Kumar *et al.* (2022) have inoculated biofertilizers like Rhizobium and PSB in vermicompost and neem cake powder. The research concluded that inoculation of vermicompost and neem cake powder with both biofertilizers showed tremendous improvement in the growth and production of baby corn over the sole application of the biofertilizers. The biofertilizers effectively supply the essential nutrients for uninterrupted metabolic activity which helps meristematic activity causing apical growth that has endorsed vigorous growth **(Jat *et al.,* 2011; Channal, 2017; Atarzadeh *et al.,* 2013)**. The results were corroborated by related studies by **Panchal *et al.,* 2018; Reddy *et al.,* 2023; Sabur *et al.,* 2021**. The application of biofertilizers enhances nutrient availability by mineralizing and mobilizing the nutrients, thereby preventing nutrient stress and amplifying growth as well as productivity of the crop when compared to conventional method of sole chemical fertilizer application **(Ramesh and Chhabra, 2023)**.

Biofertilizers are biostimulants that augment nutrient accessibility and mobilization in the soil, but it is not the complete replacement of chemical fertilizers. It condenses the need for fertilizers up to an extent but cannot fulfil the entire requirement of the plant. The crop performs better when nutrients are available in an adequate manner to complete the lifecycle **(Dewi *et***

***al.,* 2021)**. The applied fertilizers may not fulfil nutrient requirement of crop due to factors like poor solubilization, mobilization, mineralization and leaching losses. The inoculation of biofertilizers helps the plant by increasing nutrient accessibility and aiding in better crop performance in maize **(Prayogo *et al.,* 2021)**. The outcomes are in accord with **Singh *et al.* (2020)** in the onion. Seed treatment with biofertilizers boosts the performance of the crops with enhanced nutrient availability, seed protection from insects and diseases at the early germination stages, soil health and fertility. As stated by **Dewi *et al.* (2021)**, biofertilizers condense the fertilizer requirement of the crop to an extent.

The application of biofertilizers consortium reduced the applied fertilizer without affecting the growth as well as the productivity of toria in rainfed conditions in turn reducing the production cost **(Kalita *et al.,* 2019)**. Similarly increment in the rice yield was recorded by **Gohil *et al.*, 2021; Fitriatin *et al.,* 2021**. An increment in the grain and stover yield in cluster bean **(Chimate *et al.,* 2023)** and lentils **(Tiwari *et al.,* 2018**) was testified with the application of biofertilizers. Irrigation is a vital component that impacts crop production. The poor moisture regime in the soil builds the stress on the crop and also the microbial population is drastically affected. The nutrient mobilization and solubilization will be hindered by the shortage of moisture. However, concurrently when more water is applied in the form of rainfall or irrigation then it may cause nutrient leaching. The optimal moisture regime and biofertilizers will help in holding the nutrients and can be effectively utilized by the crop. The pragmatic impact of biofertilizers and optimal irrigation levels was observed in the yield of maize **(Eliaspour *et al.,* 2020)**.

2.9.3.6. Influence of biofertilizers on the improvement of soil and quality attributes of various crops

The integrated nutrient management (INM) practice helps in the effective mineralization, solubilization and increases the accessibility of the applied nutrients for the plants. The continuous nutrient supply will aid in better plant growth and productivity. The biofertilizers help in nutrient holding, ensure that nutrients are readily available in the rhizosphere and prevent nutrient losses **(Gohil *et al.,* 2021).** This aids in the effective restoration of soil nutrients in the rhizosphere. The nutrient accessibility in soil was enhanced after cultivation of rice by **Fitriatin *et al.* (2021);** oil palm **(Ajeng *et al.,* 2020)** and onion **(Talwar et al., 2017).** The biofertilizer application in the leguminous crop proved to be more beneficial because these crops have the natural nitrogen-fixing ability that improves the nitrogen availability in soil. Application of P and K biofertilizers will aid in effective nutrient restoration and enhance soil health as well as fertility **(Yadav *et al.,* 2021; Kant *et al.,* 2017)**.

Inoculation of biofertilizer accelerates microbial activity in the rhizosphere and increases nutrient accessibility to improve plant uptake. Biofertilizers help in N fixation, phosphate dissolution and also enhance PGP hormones. The phytohormones enable the plant to utilize the nutrient efficiently by prompting physiological processes like translocation and enhancing the plant nutrient uptake. The NPK fertilizers application along with biofertilizers in the soil enhances nutrient availability **(Chimate *et al.,* 2023; Meena *et al.,* 2013)**. A similar enhancement in the nutrient uptake in rice was testified by **Gohil *et al.* (2021)**. The augmented nutrient uptake and soil fertility are more prevalent in leguminous crops like lentil **(Tiwari *et al.,* 2018);** green gram **(Chahal *et al.,* 2022)** and black gram **(Kant *et al.,* 2017)** chickpea **(Yadav *et al.,* 2021)** when compared to non-leguminous crops.

2.10. Humic acid

Humic substances (HS) are residues of the decomposed plant as well as animals such as cellulose, lignin and tannins **etc (Hayes & Swift, 2020).** The harvested crop residues act as the largest reservoir of HS **(Wiesler *et al.,* 2016).** The humic substances are externally originated from organic materials, coal, soil and lignite **etc (Yang *et al.,* 2021; Gollenbeek & Van Der Weide, 2020).** Based on its solubility in different aqueous solutions, the HS is categorized into humic acids (HA) and fluvic acids (FA) **(de Melo *et al.,* 2016)**. These HA and FA can tolerate microbial reactions and chemically responsive aids in augmenting crop performance **(Billingham, 2015)**. The HA comprises about 60% organic carbon (OC) rest consists of sulphur (S), oxygen (O) nitrogen (N) and hydrogen (H) which enhances soil microbial growth **(Sible *et al.,* 2021)**. Humic acid plays a crucial role in enhancing the soil properties like structure, texture, WHC and microbial growth by increasing the physio-chemical reactions **(Nardi e*t al.,* 2021)**; improves nutrient accessibility, particularly micronutrients by chelating action in the soil **(Yang et al., 2021);** hinders the heavy metal uptake by the plant by precipitating them **(Wu *et al.,* 2017).** Humic acid promotes the production of IAA and cytokinin which enhances crop performance by curbing stress development **(de Castro *et al.,* 2021; Laskosky *et al.,* 2020)**.

2.10.1. Factors affecting the efficiency of HA

a. Source of HA

Impact of HA on the soil and crop relies on source of HS and some factors like nutrients, functional group composition and method of production **(Gollenbeek & van Der Weide, 2020; Rose *et al.,* 2014)**. Humic acid derived from various organic matters has varied bioactivity and efficacy than commercial HA in enhancing plant performance and metabolism (**Martinez-Balmori *et al.,* 2014; Arancon *et al.,* 2006).**

b. Rate of application

The application rate of HA is more efficient under stressful conditions but mainly based on the source and crop type that is grown **(Olk *et al.,* 2018; Rose *et al.,* 2014). Ali *et al.* (2020)** stated that an enhancement was observed in growth as well as protein content of maize with the upsurge in application rate of HA. Similarly, **Mohammed *et al* (2019)** reported in stevia.

c. Solubility

The solubility of HA is contingent on the pH. It is moderately soluble in water as well as the alkaline medium but precipitated in lower pH levels **(De Melo *et al.,* 2016)**. Application of water-soluble HA improved the GA activity because of the incidence of phenolic moieties **(Savy *et al.,* 2017)**. Similarly, HA has amplified the root surface area of Arabidopsis **(Schmidt *et al.,* 2007)**. Humic acid forms a stable complex with soil cations that augment the nutrient availability and physicochemical properties of soil **(De Melo *et al.,* 2016; Billingham, 2015)**.

2.10.2. Effect of HA on the plants and soil

a. Soil properties (structure, texture, pH, carbon, WHC and nutrient availability

The intensive and constant tillage operations are deteriorating the soil texture as well as the structure. The application of HA has shown some pragmatic responses on depreciated soils **(Billingham, 2015)**. The stability of soil structure has been ascribed to the amplified absorption on clay surfaces **(Chen *et al.,* 2017)** and forms chelate with cationic metals. These metals form abridged between clay surfaces and HA. Eventually enhances the soil properties **(Yamaguchi *et al.,* 2004; Billingham, 2015)**. The nutrient-holding capability is contingent on the range of cations it can retain. Humic acid plays a tremendous part in accelerating cation exchange capacity and lowering soil pH **(Laskosky *et al.,* 2020)**. Soil pH is vital as it will impact nutrient availability and mainly depends on the phenolic and carboxylic groups it possesses **(Rupiasih and Vidyasagar, 2005)**. Soil carbon content represents soil health, though HA is decomposable due to its slow breakdown nature, it constantly augments soil carbon **(Sible *et al.,* 2021).** The HA can stabilise ammonium and upsurge the N accessibility **(Zhang *et al.,* 2019; Shen et al., 2020).** The HA application has augmented ammonium and nitrate uptake in the rice **(Tavares *et al.,* 2019).** Phosphorous is a vital nutrient that synergistically impacts crop production. Humic acid application amplifies the phosphatase activity by microbes and enhances the P solubilization and eventually the P uptake **(Sharma *et al.,* 2013).** Humic acid binds sturdily to heavy metals and condenses their uptake by the plant **(Shen *et al.,* 2020).**

b. Impact of HA on the plant performance

Humic acid application in the soil helps to enhance the microbial activity in the rhizosphere, thereby promoting the synthesis of plant hormones like IAA and cytokinin as well as a few metabolic enzymes. This endorses the profuse growth of roots which increases the macro and micronutrient uptake and upsurges the chlorophyll content **(Olaetxea *et al.,* 2020; Sible *et al.,* 2021)**. Humic acid aids in moisture retention, which helps in attaining an uninterrupted supply of moisture and nutrients. This upsurges the photosynthetic activity **(Bybordi and Ebrahimian, 2013)**, translocation of photoassimilates and ultimately yield increments **(Daur & Bakhashwain, 2013; Deshmukh *et al.,* 2023;)**. **Maji *et al.* (2017)** stated an analogous plant height, shoot and root increment in the pea with the HA application. Humic acid derived from organic waste is far more effective than commercial HA and found to boost the agronomic performance of the chrysanthemum **(Fan *et al.*, 2014)**. The INM practices help to intensify crop productivity sustainably **(Sagar *et al.,* 2020; Khan *et al.,* 2010; Arjumend *et al.,* 2015)**. The HA applied at a higher rate and chemical fertilizers proved to be effective in the enhancement of plant performance **(Moghadam *et al.,* 2014; Mohammed *et al.,* 2019; Nasiroleslami *et al.,* 2021; Bera *et al.,* 2024)**.

2.11. Neem powder

With the green revolution, the focus has majorly shifted to attaining food self-sufficiency, which led to the unsystematic usage of chemicals fertilizers as well as plant protection chemicals like insecticides, pesticides and herbicides. The studies of the World Health Organization (WHO) and the United Nations Environment Programme (UNEP) explain that chemicals are sole reason for poisoning about 3 million people and leading to the deaths of 2,00,000 per year, particularly in developing countries **(Yadav *et al.,* 2015)**. The pessimistic impact of the chemicals has increased the attention towards organic management practices one of which is neem (*Azadirachta indica*) which is often referred to as the **"Life-giving tree"** and **"Divine tree"** due to its exceptional properties in the improvement of plants as well as the human health **(Hossain & Nagooru, 2011; Kumar & Navartnam, 2013)**. Because of its amazing nature, the United Nations **(UNEP, 2012)** has acknowledged the neem tree as the Tree of the 21st Century. Every part of the plant is beneficial for crop production and protection. The neem extract includes root extract, neem gum, neem oil, bark extracts and leaf extracts that contain organic manure, fungicide and bio-pesticide **(Acharya *et al.,* 2017)**.

The neem powder extract acts as a better plant protectant because its repellent nature aids in bactericidal, fungicidal, nematocidal and insecticidal properties **(Pascoli *et al.,* 2019).** When neem powder is soil amended it helps as a soil enricher, growth promoter, promotes nutrient content, hinders pest, disease, insect growth and eventually enhances the productivity of plants **(Roshan & Verma, 2015)**. It also acts as a biofertilizer and enriches the rhizosphere by preventing nutrient leaching and enchases their availability **(Lokanadhan *et al.,* 2012).** According to **Das *et al.* (2018),** the neem powder has enhanced the productivity of ginger, cardamom and turmeric. Also, better nutrient management practices in maize, rice, soybean, rapeseed and wheat **(Das & Avasthe, 2020).** Neem powder has hindered the incidence of fall armyworm in maize **(Silva *et al.,* 2015)** nematode of black pepper **(Sathyan *et al.,* 2020)** and post-harvest deterioration during the stage of storing rice **(rice weevil) (Jahan *et al.,* 2019).** It also controls the aphid and caterpillar growth **(Bhatta *et al.,* 2019; Parajuli *et al.,* 2020).**

2.12. Impact of crop geometric strategies on economics

Integrating crop geometry (normal spacing and paired row spacing) and seed capsules (which consist of seed, neem powder, humic acid and NPK biofertilizers) offers multiple economic benefits to farmers by optimizing resource use, improving crop productivity and reducing input costs. Paired row spacing contrary to normal spacing ensures optimal plant population density, leading to higher yield per unit area while maintaining good aeration and sunlight penetration, ultimately enhancing photosynthesis and growth (**Abdo *et al.,* 2022; Khan *et al.,* 2019**). Effective resource utilization and yield optimization aid in enhancing the farmer's income and provide a monetary advantage within the available resources (**Qodliyati& Nyoto, 2018; Bernhard & Below, 2020**). The use of seed capsule ensures precise seed placement and prevents overseeding, thereby reducing the seed rate and cost incurred by seed by 15-30% (**Jha *et al.,* 2020**). With better germination rates and controlled nutrient release from biofertilizers, crops receive essential nutrients at the right stages, leading to stronger root development and improved plant vigour (**Tiwari *et al.,* 2018**). The slow-release mechanism of NPK biofertilizers helps reduce nutrient leaching and volatilization, thereby cutting down fertilizer requirements by 30-40% leading to significant cost savings for farmers (**Talwar *et al.,* 2017; Djajadi *et al.,* 2019; Yadav *et al.,* 2021**).

Additionally, the neem powder in the capsule acts as a natural biopesticide, protecting young plants from pests and diseases without relying on expensive chemical pesticides at the early stages of the crop (**Pascoli *et al.,* 2019**). This reduces pesticide requirements making crop protection more affordable and environmentally friendly (**Roshan & Verma, 2015; Das & Avasthe, 2020**). The inclusion of HA further enhances soil structure, microbial activity and nutrient availability, promoting long-term soil fertility. HA ensures uniform crop establishment, which enhances productivity (**Daur & Bakhashwain, 2013**). Over time, this approach decreases dependence on synthetic fertilizers, leading to lower farming costs and improved sustainability (**Sagar** ***et al.,*** **2020**). The combined effect of optimized spacing, nutrient efficiency and reduced pest damage ensures higher marketable yield with improved grain quality, fetching better prices in the market (**Rani** ***et al.,*** **2020**). This integrated approach leads to 15-30% increase in net profitability, driven by higher yields, reduced input costs, improved soil health, and lower labour expenses (**Srilathavani** ***et al.,*** **2020**). By adopting effective spacing practices and seed capsules farmers can achieve sustainable, cost-effective and higher maize production, making agriculture more profitable in the long run.

CHAPTER – III
MATERIALS AND METHODS

CHAPTER -III
MATERIALS AND METHODS

A research trial was executed to investigate the different hydrogel levels and crop geometric strategies in the spring maize. This chapter describes the methodologies, materials and techniques espoused throughout the research entitled "**Agronomic evaluation of crop geometry and irrigation strategies on performance of spring maize (*Zea mays* L.)**"

3.1. Location of the experimental site

The study was carried out during the spring season of 2022 and 2023 at the agronomy research farm of the Department of Agronomy, School of Agriculture, Lovely Professional University (LPU), Phagwara, Punjab (India). The experiment site is located at 31°24′ N and 75º69′ E and 234 m height from the mean sea level (MSL). The experiment site coordinates fall under the Central Plain Zone of Punjab (fig. 3.1).

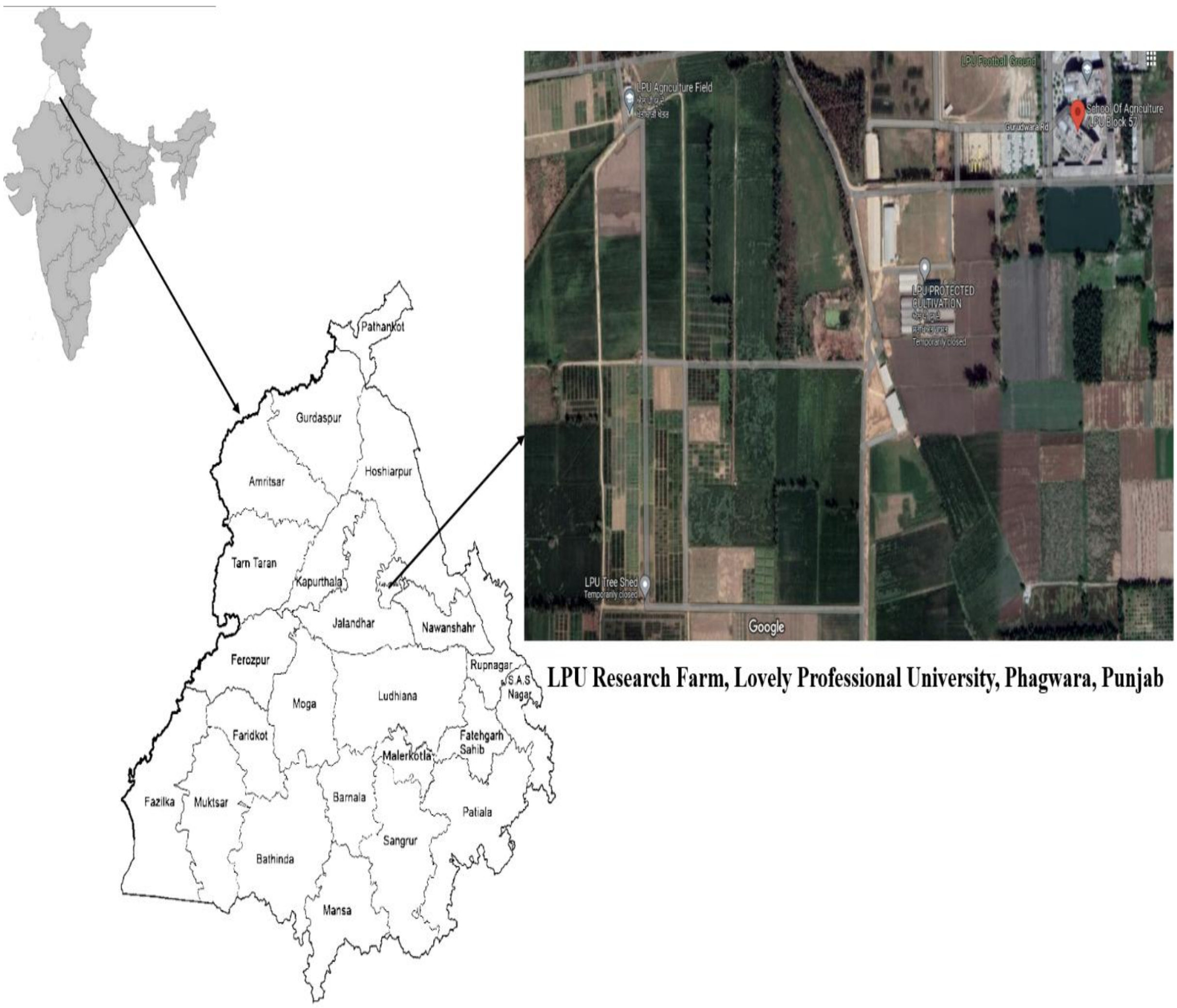


Fig. 3.1. Location of the experimental trial site.

3.2. Soil characteristics of experimental site

Five soil samples were randomly acquired from the experimental site at a depth of 0-15 cm. The collected soil samples were mixed thoroughly to make a composite sample i.e., final sample. The soil sample was sieved with the help of a 2 mm sieve to remove clods etc after proper drying. For the measurement of the soil chemical properties, the samples are analysed by employing the standard methods as shown in Table. 3.1.

Table. 3.1. Chemical properties of soil at the experimental site.

S No.	Property	Value		Method
Chemical properties				
		2022	**2023**	
1	pH	7.8	8.1	**Jackson, 1958**
2	Electrical conductivity (dSm^{-1})	0.11	0.16	**Jackson, 1958**
3	Organic carbon (OC) (%)	0.39	0.42	**Walkley & Black, 1934**
4	Nitrogen (N) (kg/ha)	206.85	209.13	**Subbaiah & Asija, 1956**
5	Phosphorous (P) (kg/ha)	23.72	23.88	**Olsen *et al.,* 1954**
6	Potassium (K)(kg/ha)	165.6	167.1	**Jackson, 1973**

3.3. Cropping history

Different crops grown in the preceding seasons and during the period of the experiment are incorporated and presented in table 3.2.

Table. 3.2. Experimental site cropping history.

Year	Cropping season		
	Kharif	***Rabi***	***Spring***
2021	Rice	Wheat	Fallow
2022	Brinjal	-	Maize trial - 1
2023	Greem gram	Fallow	Maize trial - 2

3.4. Climate and weather situation

The experimental site is located in the northern hemisphere with climatic conditions classified as mild and moderate. Most of the rainfall is due to the south-west monsoon and a small amount of rainfall is due to the western disturbances during February and March. The average yearly precipitation of 816 mm is recorded. July and August are months where more precipitation is recorded, while August is the most humid month. December and January are the coolest months of the year. An average maximum temperature of more than 30ºC recorded from April to October with April, May and June being the hottest months.

The weather variables like average weekly maximum as well as minimum temperature, total rainfall in a week (mm), no. of rainy days per week and relative humidity recorded by meteorological observatory located at research farm, School of Agriculture, LPU, Phagwara, Punjab, are included. The climatic conditions that prevailed throughout the cropping seasons of the experiment (spring season 2022 and 2023) are depicted in appendix- 1. The fluctuating and varied temperatures was recorded throughout the cropping seasons viz. 2022 and 2023. The maximum mean temperature (41.2ºC) and minimum mean temperature (9.3ºC) in the experimental area were recorded in the year 2022, whereas the values were 42.9ºC and 13.8ºC in the year 2023.

Gross rainfall of 98.3 mm and 215.64 mm was recorded in the years 2022 and 2023. The amount of rainfall varied from first year to the second year. Four out of 17 standard meteorological weeks (SMW) of rainfall were recorded in 2022. While 13 out of 17 SMW of rainfall were recorded in 2023. In the cropping season of 2022, a very good amount of rainfall was recorded in the 9^{th}, 21^{st} and 25^{th} SMW with 16 mm, 11.2mm and 70.6 mm of heavy rainfall respectively. However, a light rainfall of 0.5 mm was recorded in the 15^{th} SMW. In contrast to 2022, the 2023 cropping season had frequent rainfall throughout the season with only a few dry spells of SMW. In the 11^{th}, 12^{th}, 16^{th}, 21^{st}, 22^{nd}, 23^{rd}, 24^{th} and 25^{th} SMW, heavy rainfall of 15 mm, 38.40 mm, 9.30 mm, 14.20 mm, 39.40 mm, 23.60 mm, 41.60 mm and 16.20 mm were recorded respectively. Moderate rainfall of 5.70 mm and 7.60 mm was recorded in the 18^{th} and 20^{th} SMW respectively and light rainfall of 0.02 mm, 2.22 mm and 2.40 mm in the 9^{th}, 13^{th} and 14^{th} SMW respectively was recorded. No rainfall was recorded in the 10th,15th, 17th, and 19th SMW. During the cropping season of 2022, only 5 rainy days were recorded. In contrast to 2022, 30 rainy days were recorded during the cropping season in 2023 i.e., 1/4th of the cropping season (30 days out of 120 days) has received rains. This might be the reason for the occurrence of moderate temperatures even during the peak summer months of April and May of 2023. Whereas in 2022, there were heavy heat waves due to the occurrence of less rainfall where temperatures increased up to 30ºC in the non-conventional hot months like March.

3.5. Experiment details

3.5.1. Field experiment

An experiment field trial was conducted during the spring season 2022 and 2023, on test crop maize (*var*. PMH-10) as follows.

3.5.2. Characteristics of crop variety

PMH-10 (Punjab Maize Hybrid-10) is a high-yielding, single-cross hybrid maize variety developed by Punjab Agricultural University (PAU), Ludhiana, Punjab. This hybrid matures in about 100 to 110 days, exhibits semi-dent grain type and semi-hard texture with attractive yellow kernels. PMH-10 is known for its tolerance to lodging. The variety exhibits a moderate plant height (around 190–220 cm) and good synchronization between tasselling and silking, which contributes to better pollination, medium-long, cylindrical cobs with good grain filling. The variety has a yield potential of 8-10 tonnes/ha under optimal conditions.

3.5.3. Design and layout of experiment

The field trial was executed in the split-plot design by randomizing the subplots with twelve treatments replicated thrice.

Table. 3.3. Experiment details.

Year of the experiment	2022 and 2023
Crop	Maize (*var*. PMH-10)
Experimental design	Split-plot design
No. of treatments	12
No. of replications	3
Total no. of plots	36
Size of plot	$5.6 \times 5.6 = 31.36m^2$
Width of main irrigation channel	1 m
Width of bunds	0.6 m
Total length of the experimental plot	78.2 m
Total width of the experimental plot	20.6 m
Gross cultivated area	1751.7 m^2
Net cultivated area	1129 m^2
Spacing	As per the treatment combination
Fertilizer	N: P: K kg/ha at the 120:60:40 kg/ha (as per Punjab Agricultural University (PAU) recommendation)

Table. 3.4. Experimental factors.	
Treatments	**Symbol**
A. Hydrogel levels	
Without hydrogel application in the soil (0 kg/ha)	H_1
With hydrogel application in the soil (1.5 kg/ha)	H_2
With hydrogel application in the soil (3 kg/ha)	H_3
B. Crop geometric strategies	
Normal spacing (70 × 25 cm)	C_1
Paired-row spacing (55 - 85 × 25 cm)	C_2
Normal spacing with the seed capsule (70 × 25 cm)	C_3
Paired-row spacing with the seed capsule (55 - 85 × 25 cm)	C_4

Note: *Seed capsule:* Each gelatine capsule is filled with 1 maize seed, humic acid powder, IFFCO N, P and K consortia biofertilizer and neem powder at 3 kg/ha, 3 kg/ha and 2 kg/ha respectively. While filling capsules the components were slightly overfilled in the filling tray and then by a scraping tool, the excess component mixture was removed to ensure a consistent and uniform fill level in all capsules. Flood irrigation was given to the main plots only as per the requirement of the individual main plots by analysing the moisture conditions using the touch method. In this method, soil moisture content was analysed with the following criteria: **Wet soil- Feels** sticky and retains shape when pressed; **Moist soil- Forms** a ball but crumbles when pressed lightly and **Dry soil:** Feels loose, powdery and does not form a ball when squeezed. The decision to provide irrigation was made with the help of the above criteria, i.e., when the topsoil feels dry and also considering the recorded weather conditions between the irrigation intervals.

Table. 3.5. Treatment combinations of the experiment.			
S. N.	**T. N.**	**Treatment combination**	
1	T_1	H_1C_1	Hydrogel 0 kg/ha + normal spacing (70 × 25 cm)
2	T_2	H_1C_2	Hydrogel 0 kg/ha + paired row spacing (55-85 × 25 cm)
3	T_3	H_1C_3	Hydrogel 0 kg/ha + normal spacing (70 × 25 cm) with seed capsule
4	T_4	H_1C_4	Hydrogel 0 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule
5	T_5	H_2C_1	Hydrogel 1.5 kg/ha + normal spacing (70 × 25 cm)
6	T_6	H_2C_2	Hydrogel 1.5 kg/ha + paired row spacing (55-85 × 25 cm)

7	T_7	H_2C_3	Hydrogel 1.5 kg/ha + normal spacing (70 × 25 cm) with seed capsule
8	T_8	H_2C_4	Hydrogel 1.5 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule
9	T_9	H_3C_1	Hydrogel 3 kg/ha + normal spacing (70 × 25 cm)
10	T_{10}	H_3C_2	Hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)
11	T_{11}	H_3C_3	Hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule
12	T_{12}	H_3C_4	Hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule

3.6. Pre-harvest and post-harvest cultural operations

The calendar of operations carried out during the experiment was presented chronologically in table 3.6.

3.6.1. Germination test

Maize seeds were tested for germination efficiency before the sowing. Twenty seeds were taken for the germination test and allowed to germinate in a petri plate under lab conditions by using filter paper. A good germination percentage of 95% was recorded.

3.6.2. Field preparation

The field was first ploughed with the rotavator for pulverizing the soil to break large clods and the cultivator was drawn followed by the planking of the field.

3.6.3. Layout preparation

After proper tillage operations, the layout was prepared as shown in fig. 3.2. Initially, the main ridges were made with a bund maker which includes the irrigation channels along the length (78.2 m) and horizontal bunds at both ends with a width of 22.4 m. Next, the individual plots were divided with a length of 5 m for each plot and a bund of 0.6 m width was maintained between two plots, with a net plot size of 31.36 m^2 each. A buffer zone of 1 m was created between the main plots, to avoid the overflow of irrigation water into other main plots that are not irrigated at the same time and to maintain accurate irrigation strategies.

3.6.4. Nutrient management

The application of major nutrients like N, P and K was done in the form of urea, di-ammonium phosphate (DAP) and muriate of potash (MOP). Doses of N: P: K (120: 60: 40 kg/ha respectively) were applied as per recommendations of Punjab Agricultural University, Ludhiana. Hundred percent of P and K, whereas 50 % of N was given as a basal dose by broadcasting the fertilizer and light mixing in the topsoil to avoid direct exposure to the atmosphere. The rest of N was top dressed in three splits at 45, 60 and 75 DAS to maintain uniform availability of nutrients during late vegetative and early reproductive stages.

3.6.5. Sowing

A seed rate of 25 kg/ha of variety PMH-10 was used for sowing. The dose of hydrogel was broadcasted in the plots as per the treatment combinations and racking was done for uniform distribution in the plot. The variety chosen for the experiment was a hybrid that exhibits more vigorous growth and requires additional space. Hybrids are more susceptible to diseases and pests so proper disease management is necessary which can be attained by increasing spacing. More space permits hybrids to achieve their full potential in terms of growth and yield. Considering the above-mentioned reasons the conventional spacing (60 × 20 cm) was modified by increasing row-to-row spacing by 10 cm and plant-to-plant spacing by 5 cm. The sowing of maize was done as per the spacing mentioned in the treatment combination i.e., normal spacing (70 × 25 cm) and paired row spacing (55-85 × 25 cm). In normal spacing (70 × 25 cm), the 70 cm row-to-row distance was maintained and the plant-to-plant distance was 25 cm as shown in fig 3.3. Whereas in the paired row spacing, two rows were brought together with a distance of 55 cm to make a pair and of 85 cm distance was maintained between the two pairs as shown in fig 3.4.

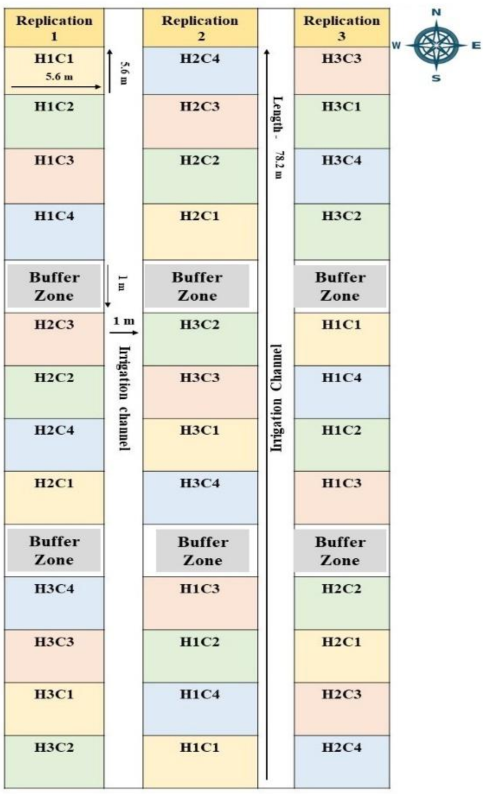


Fig. 3.2. Layout of the experimental site.

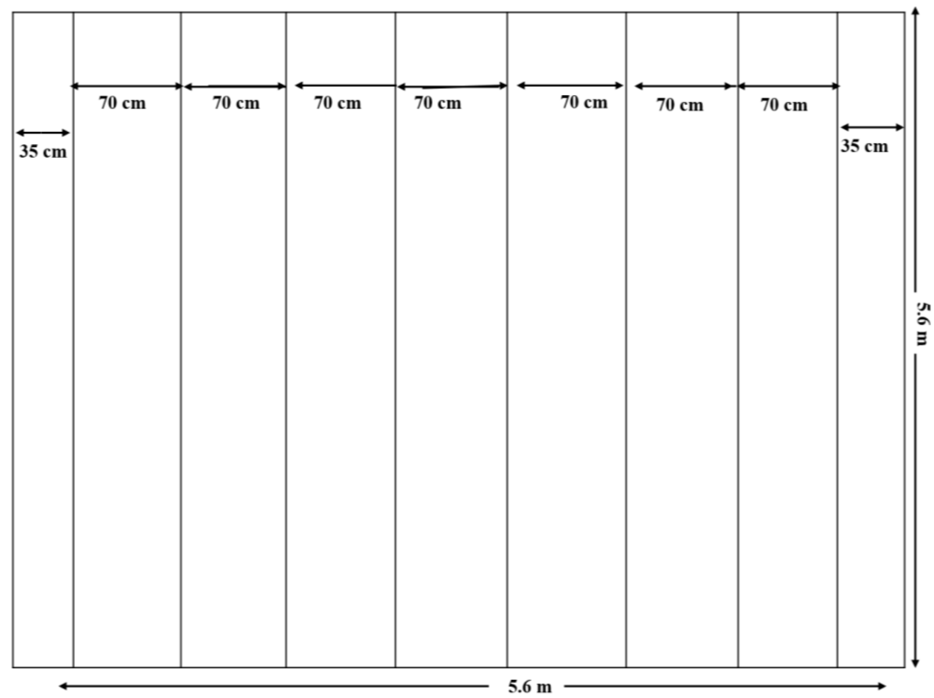


Fig. 3.3. Plot depicting the normal spacing (70 × 25 cm).

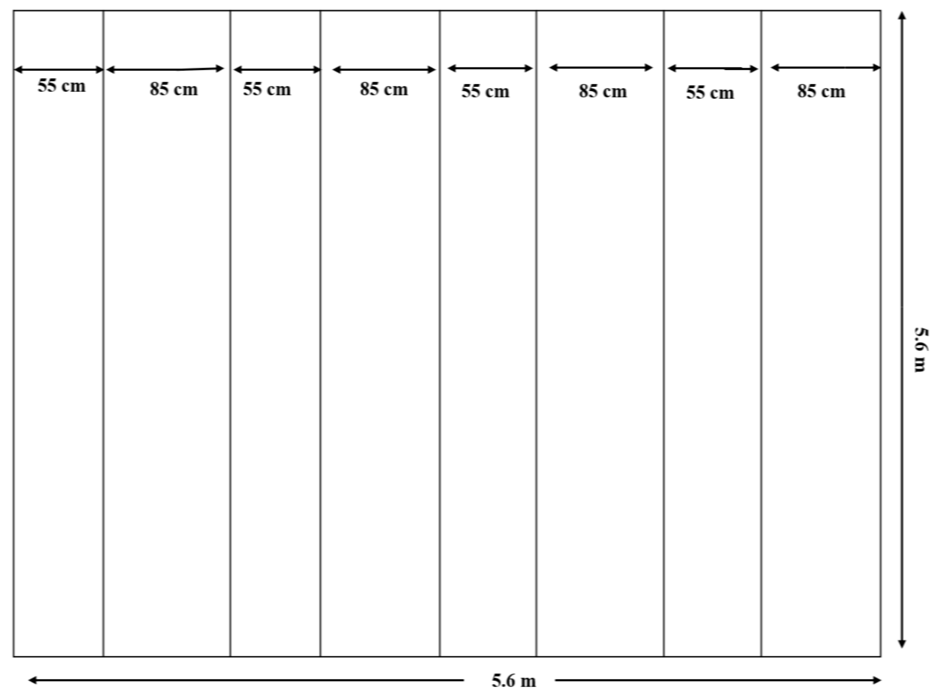


Fig. 3.4. Plot depicting the paired row spacing (55-85 cm × 25 cm).

3.6.6. Weeding

To control the weeds, the spray of pre-emergence herbicide (atrazine) at a rate of 1.2 kg/ha was done after sowing. For the control of *Cyperus rotundas*, the herbicide Sempra was sprayed at a rate of 90g/ha at 25 DAS. One manual weeding was done during the cropping period at 45 DAS.

3.6.7. Irrigation

The irrigations as a part of irrigation strategies were given as per the requirement of the crop and field conditions. The number of irrigations and irrigation intervals are mentioned in chapter 4 i.e., Results and discussions, while the irrigation schedule is presented in table 3.7.

Table. 3.6. Chronological record of agro-techniques implemented (Calendar of operations) during the experiment.

S. no	Operation done	2022		2023	
		Date	DAS	Date	DAS
1	NPK biofertilizers inoculation in humic acid for incubation	9/02/22	-16	9/02/23	-16
2	Preparation of seed capsules	23/02/22	-2	23/02/23	-2
3	Preparation of land and layout	24/02/22	-1	24/02/23	-1
4	Basal dose of fertilizers application	25/02/22	0	25/02/23	0
5	Sowing	25/02/22	0	25/02/23	0
6	Pre-herbicide spray (Atrazine)	28/02/22	3	27/02/23	2
7	Herbicide spray (Sempra)	22/03/22	25	22/03/23	25
8	**Hand weeding**				
a	1st hand weeding	11/04/22	45	11/04/23	45
9	**Pheromone trap installation**				
a	Fall army worm (*Spodoptera frugiperda*)	17/03/22	20	17/03/23	20
b	Earworm (*Helicoverpa zea*)	29/03/22	32	29/03/23	32
c	Stalk borer (*Chilo partellus*)	11/04/22	50	11/04/23	50
10	Spray of emamectin benzoate	26/04/22	65	26/04/23	65
11	**Top dressing**				
a	1st top dressing	06/04/22	45	06/04/23	45
b	2nd top dressing	21/04/22	60	21/04/23	60
c	3rd top dressing	05/05/22	75	05/05/23	75
12	Harvesting	19/06/22	115	17/06/23	113
13	Threshing	22/06/22	118	20/06/23	116

Table. 3.7. Chronological record of irrigation schedule during the experiment.													
S. no	Irrigation number	Main plot (H_1)				Main plot (H_2)				Main plot (H_3)			
		2022	**DAS**	**2023**	**DAS**	**2022**	**DAS**	**2023**	**DAS**	**2022**	**DAS**	**2023**	**DAS**
1	1st irrigation	27/02/22	03	27/02/23	03	27/02/22	03	27/02/23	03	27/02/22	03	27/02/23	03
2	2nd irrigation	10/03/22	14	07/03/23	11	12/03/22	16	11/03/23	15	15/03/22	19	13/03/23	17
3	3rd irrigation	16/03/22	20	15/03/23	19	20/03/22	24	11/04/23	46	26/03/22	30	11/04/23	46
4	4th irrigation	24/03/22	28	11/04/23	46	28/03/22	32	27/04/23	62	07/04/22	42	13/05/23	78
5	5th irrigation	02/04/22	37	25/04/23	60	06/04/22	41	10/05/23	75	20/04/22	55		
6	6th irrigation	10/04/22	45	06/05/23	71	18/04/22	53			30/04/22	65		
7	7th irrigation	18/04/22	53	20/05/23	85	27/04/22	62			14/05/22	79		
8	8th irrigation	26/04/22	61			05/05/22	70			04/06/22	100		
9	9th irrigation	03/05/22	68			14/05/22	79						
10	10th irrigation	10/05/22	75			01/06/22	97						
11	11th irrigation	19/05/22	84			11/06/22	107						
12	12th irrigation	01/06/22	97										
13	13th irrigation	09/06/22	105										

3.6.8. Harvesting

The maize crop was harvested after attaining maturity when straw and husk of cob turned yellow and the available grain moisture reached 15%. From the whole net plot, the crop was harvested. The straw bundles were prepared with proper labelling and each bundle was weighed for recording biological yield. Cobs were separated from the straw and threshing of harvested cobs was done after complete sun drying.

3.6.9. Threshing

Threshing of the maize was done manually by separating the grains from the cob. Later on, the grains were winnowed to remove impurities and packed separately to avoid the mixing of the grains of different treatments. The weight of the individual plot was recorded for grain yield.

3.7. Collection of the experimental samples

3.7.1. Soil sampling

Before sowing, soil samples were collected randomly from the five spots, and they were thoroughly mixed to make a composite sample.

3.7.2. Plant sampling

Plant sampling was done at 25, 50, 75 and 100 days after sowing, at maturity and harvest. Three plants from the centremost part of the plot were randomly selected for sampling purposes by avoiding the first two rows on both sides and also the 4 plants of a row on both sides. The criteria for selection of representative plants from the centre of the plot was due to less exposure of plants to external factors like wind, infestations etc., The accuracy of plant spacing, light availability, more consistent availability of fertilizers, irrigation, crop protection practices with more precision and reliability of field observations. These representative plants were tagged and used to record the observations related to growth and pre-harvest yield attributes. The final data was prepared by taking the mean value of observations from the representative plant of each plot. The plant samples collected for laboratory analysis were first air-dried to enhance their shelf life and then stored in zip-lock polybags as per the treatments.

3.7.3. Observations recorded

1. Growth parameters

a. Plant height (cm)

Plant height was recorded at 25, 50, 75 and 100 DAS. The measurement was taken from the base (ground level) to the node tip of flag leaf till the vegetative phase and base tip of the tassel after tasselling.

b. **Number of leaves per plant**

The leaf count per plant was recorded at 25, 50, 75 and 100 DAS.

c. Stem girth (cm)

Stem girth was measured at 25, 50, 75 and 100 DAS with the help of a ruler and a thread. At the base of the stem, the thread was placed from a point on the stem and made a circle. The distance between the two points on a thread where it was started and the endpoints coincide was recorded and represented in cm.

d. **Stem diameter (cm):**

Stem diameter was obtained from the stem girth by using the formula given below.

$$\textbf{Stem diameter} = \frac{\textbf{Stem girth}}{\textbf{3.14}}$$

2. **Yield parameters**

a. No. of cobs per plant

The cob count per plant from each plot was recorded at the physiological maturity stage on the representative plants.

b. Length of cob (cm)

After the harvesting of the cobs, the husk of the cob was removed and the cob length was measured from the base to the tip of the cob.

c. No. of rows per cob

The vertical grain rows were counted along the cob length from representative plants.

d. No. of grains per row of cob

The grain count per row of the cob was recorded in each cob from the representative plant of each plot.

e. Weight of cob (with husk) (g)

The cob weight (g) along with the husk (including the green husk and silk) was recorded from the representative plant of each plot.

f. Weight of cob (without husk) (g)

The cob weight (g) without the husk (after removing the green husk and silk) was recorded from the representative plant of each plot.

g. Cob girth (cm)

Firstly, the husk as well as the silk of the cob were removed. With the help of measuring tape, the cob girth was measured from the representative plants of each plot.

h. Seed index (g)

After the separation of the grains, the hundred-grain weight (g) was recorded.

i. Grain yield (t/ha)

The crop was harvested after attaining physiological maturity. The cobs from the harvested plants of the net plot area were separated. After proper sun drying, cobs were threshed. The separated grains were winnowed to remove the impurities. Then the yield was measured and the obtained yield from each plot was computed to 1 hectare.

j. Straw yield (t/ha)

After harvesting the crop from net plot area, the straw of the plant was separated and bundled. Later on, the straw bundles were weighed from each plot and computed to 1 hectare.

k. Biological yield (t/ha)

The above-ground biomass (grain as well as straw yield) of crop from net plot area. The biomass weight was recorded before the cob separation from each plot and computed to 1 hectare.

l. Harvest index (HI) (%)

The HI was computed with the below-mentioned formula and expressed in percent (%).

$$\textbf{Harvest index (\%)} = \frac{\textbf{Grain yield}}{\textbf{Biological yield}} \times \textbf{100}$$

m. Shelling percentage with husk (%)

Shelling percentage was calculated by the formula given below.

$$\textbf{Shelling percentage with husk (\%)} = \frac{\textbf{Grain weight of cob}}{\textbf{Cob weight with the husk}}$$

n. Shelling percentage without husk (%)

Shelling percentage was calculated by the formula given below.

$$\textbf{Shelling percentage without husk (\%)} = \frac{\textbf{Grain weight of cob}}{\textbf{Cob weight without husk}}$$

3. 8. Soil studies

a. Determination of soil pH and EC

The pH and EC were recorded with help of a pH meter and electrical conductivity meter respectively **(Jackson, 1958)**. The collected soil samples were properly dried. To a 100 ml beaker, the 10 g soil was added. Thereafter 25 ml of distilled water was also added to the beaker. The solution was thoroughly stirred with the help of a glass rod and left for about 30 min to attain the state of equilibrium.

b. Organic carbon (OC)

The estimation of OC in the soil was executed as per the guidelines of **Walkley & Black, (1934)**. In a conical flask, one gram of dried soil, 20 ml of concentrated sulfuric acid

(H_2SO_4) and 1N solution of potassium dichromate ($K_2Cr_2O_7$) was added. The flask was shaken for 2 minutes and left in a still position for half an hour to complete the reactions. To the suspension of distilled water (200 ml), ten ml of orthophosphoric acid (H_3PO_4) (85%) and 1 ml of diphenylamine indicator were added. The solution was titrated with ammonium ferrous sulphate and titration point was noted with a change in colour from purple to green. A blank sample was also titrated in the same manner.

c. Available nitrogen in the soil

The estimation of available N in soil was done according to the alkaline potassium permanganate method **(Subbaiah & Asija, 1956)**, where oxidation of soil organic matter was carried out. Twenty grams of soil was taken in the distillation flask, where 100 ml of 0.32% $KMnO_4$ solution and 20 ml of water were added. Boric acid (20 ml) was prepared in a volumetric flask of 250 ml capacity and 4-5 drops of methyl red indicator were added to it. The receiving tube was positioned beneath the flask. In boric acid solution, the tip of the receiver tube was dipped. The distillation flask having the soil, 2.5% NaOH and 100 ml of 0.32% $KMnO_4$ was connected the flask to the distillation apparatus. The released ammonia during the distillation process was absorbed in the boric acid solution. Sample was removed after the distillation. The burette was filled with 0.02 N H_2SO_4 and boric acid solution was titrated till the pink colour appeared. Both initial and final readings were noted down.

Formulae for available soil N calculation (kg/ha

$$\frac{\mathbf{R \times 0.002 \times 14 \times 2.24 \times 10^{6}}}{\mathbf{W \times 100}}$$

Where R is the reading of blank, 0.002 = Normality of H_2SO_4, 14 = Atomic weight of N, 2.24 $\times 10^6$ = weight of the one-hectare soil, W = weight of the soil.

d. Available phosphorous in the soil

The available P in soil was assessed by the chlorostannous reduced phosphomolybdate blue colour method **(Olsen *et al.,* 1954).** The five-gram soil sample, a spoon of Darco G-60 (phosphorous-freed activated charcoal) and 100 ml of 0.5 M sodium bicarbonate ($NaHCO_3$) were added to a 250 ml volumetric flask. The flask was shaken for approximately 25-30 minutes with the help of a mechanical shaker. By using Whatman's no.1 paper the suspension was filtered. Five ml of filtrate, ammonium molybdate and 10 ml of distilled water were taken in a volumetric flask of 25 ml. One ml of working $SnCl_2$ solution was taken in a flask of 25 ml and the final volume of 25 ml was made by adding distilled water. The blue colour absorbance was recorded by spectrophotometer at 660 nm and can be obtained within 5-20 minutes of adding $SnCl_2$. The same process was executed for the blank.

e. Available potassium in the soil

The available K was assessed in soil sample with the flame photometer (**Jackson, 1973)**. Five grams of soil and 25 ml ammonium acetate (NH_4OAc) solution were taken in a 250 ml flask. The flask with a mechanical shaker was shaken for 10 minutes. The pH was adjusted to 7.0 using a pH meter. The suspension was filtered by using whatman's paper no. 1. The readings were recorded with the help of a flame photometer.

f. **Number of irrigations and irrigation intervals**

The number of irrigations applied and irrigation interval between two irrigations were recorded. They are mentioned in table 4.29, while the irrigation schedule is presented in table 3.7.

3.9. Quality studies

a. **Estimation of total nitrogen concentration in plant sample**

The plant samples (grain and straw sample) of 0.5-1 g were taken in a 250 ml digestion tube along with a 20 ml mixture of sulphur-salicylic acid. To remove any leftover sample in the tube, it was rotated and was left without any disturbance for about 2 hours. Sodium thiosulphate (2.5g) was added to the tube, shaken for a few minutes and left standing overnight. 4 granules of pumice and a catalyst mixture of 4g were mixed and the tube was kept on the block digester pre-heated at 400ºC. To ensure accurate digestion and constrain the loss of H_2SO_4, a small funnel was placed at the mouth of the tube and endured till the mixture became transparent. After the digestion, the tubes were left to cool for 20 minutes. The tubes were again kept in a block digestor for 2 hours after thorough shaking. The volume of 250 ml solution was made by adding the distilled water to the digested samples. Each set of samples consists of at least one blank reagent and one standard plant sample. Digested samples were titrated with 0.1 N H_2SO_4 till the development of purple colour.

b. Estimation of total phosphorous and potassium concentration in plant sample

The vando-molybdate phosphoric acid yellow colour method was used for quantification of phosphorous content in the plant samples **(Jackson, 1973).** The plant samples (grain and straw sample) of 0.5-1 g were weighed and kept in a 250 ml digestion tube along with a di-acid (HNO_3 + $HClO_4$) mixture of 10 ml. The samples were digested in KEL plus digestion block at 150ºC. The digested samples were shifted to the 100 ml flask and by adding the distilled water the volume was made up to the 100 ml mark. Ten ml of digested sample and 10 ml of vando-molybdate reagent were added to a volumetric flask and 50 ml volume was made by adding the distilled water. The colour intensity of the solution was recorded with the help of a spectrophotometer. Flame photometer was used for the estimation of potassium **(Chapman and Pratt, 1961).**

c. Estimation of protein content in grains

The grain protein content was estimated by Bradford protein assay **(Bradford, 1976).** The grains were thoroughly washed to remove impurities and the grains were ground to powder form. The following reagents were used for the extraction and quantification of protein content in the grains.

- **Extraction buffer:** It was prepared by NaCl (50mM), EDTA (5mM) and NaH_2PO_4 (25mM). The final volume of 100 ml was prepared by mixing all the reagents in a conical flask and a pH of 7.2 was maintained.
- 1 gram of powdered grain sample was added to a conical flask and stirred with a cold extraction buffer of 5 ml. For 20 minutes at 10,000 g at 2ºC, the mix was centrifuged.
- **Bradford dye:** In 50 ml of 95 % ethanol, Coomassie-brilliant blue G-250 (100 mg) was dissolved. After that 100 ml of 85% H_3PO_4 was mixed in it and a final volume of 1000 ml was prepared with the help of distilled water. In a dark-coloured bottle at 4ºC, the prepared solution was stored after filtration.
- **BSA standard solution:** 10 mg of BSA was dissolved in 10 ml double distilled water for the preparation of (BSA) stock solution.
- **Standard curve preparation:** Five test tubes were prepared in series (0.2, 0.4, 0.6, 0.8 and 1.0 ml) from standard solution of BSA and a final volume of 1 ml was made. A test tube with 1 ml of distilled water acts as a blank. To each test tube, five ml of dye was added and mixed thoroughly. Absorbance was recorded at 595nm by using the spectrophotometer after 10-30 minutes. The standard curve was depicted in Appendix.7.
- One ml aliquot of plant sample and 5 ml dye were added to the test tube. Proper mixing was done and left for 10-30 minutes. The absorbance was recorded by using the spectrophotometer at 595 nm.

d. Grain appearance score

The grain appearance score is an important parameter that defines the price of the produce. The main characteristics to check the grain appearance score are size, shape and luster of grain (shining). Size can be small, medium and large; shape can be based on the shrivelling: completely shrivelled, moderately shrivelled and no shrivelling. Luster is the shining of the grain: poor luster, moderate luster and full luster are taken. Three cobs from each plot were taken and five grains from each cob were assessed for their characteristics on a scale of 1-3 score individually. The obtained score from all the characteristics was taken and an average was done to obtain the final grain appearance score.

3.10. Economics

The monetary parameters like cost of cultivation, gross return, net return as well as benefit: cost ratio (B: C ratio) were calculated to compute the economics of each treatment combination based on the current market price of input and output of the experiment.

a. Cost of cultivation(₹/ha)

The cost of cultivation (₹/ha) of each treatment (inclusive of variable cost of hydrogel, irrigation labour cost, seed capsules and their filling and fixed cost involved) was computed based on all operations done.

b. Gross return (₹/ha)

The gross return (₹/ha) of each treatment was computed based on minimum support price of the maize crop and yield obtained after the experiment.

c. **Net return (₹/ha)**

The net return (₹/ha) of each treatment was computed as per the equation given below.

Net return = Gross return (₹/ha) - Cost of cultivation (₹/ha)

d. Benefit-cost ratio (B: C ratio)

The B: C ratio was calculated by using the following equation, which shows the profit gained with respect to the rupee spent on the experiment. The ratio of 1 indicates no profit no loss, a value higher than 1 indicates profit and less than 1 indicates loss. The B: C ratio equation is as follows.

$$\textbf{Benefit: cost ratio} = \frac{\textbf{Net return (₹/ha)}}{\textbf{Total cost of cultivation (₹/ha)}}$$

3.11. Statistical analysis

The data on the various variables obtained from the experiment were subjected to analysis of variance (ANOVA) as per the standard protocols using R studio statistical computing software. The efficacy of the treatments on all the parameters in the current study was compared by using the "F"-test at 5% level of significance.

CHAPTER - IV
RESULT
AND
DISCUSSION

CHAPTER -IV

RESULTS AND DISCUSSION

The observations and findings of the current experiment titled "**Agronomic evaluation of crop geometry and irrigation strategies on performance of spring maize (*Zea mays* L.)**" are tabulated, visualised and discussed in the present chapter.

4.1. Impact of irrigation and crop geometric strategies on the growth and yield parameters of spring maize

4.1.1. Crop growth parameters

The employment of hydrogel levels and crop geometry has influenced the vegetative growth of the spring maize. The growth attributes i.e., plant height (cm), number of leaves, stem girth (cm) and stem diameter (cm) are presented in tables, figures and discussed below.

4.1.1.1. Plant height (cm)

The data related to the impact of hydrogel levels and crop geometric strategies on plant height of spring maize is depicted in tables 4.1- 4.5. During the first year (2022) of study, hydrogel levels have significantly shown their influence on the improvement of plant height. The highest plant height of 14.0, 64.1, 131.3 and 171.2 cm was recorded at the 25, 50, 75 and 100 DAS respectively under H_3. On average, the lowest plant height of 9.8, 45.6, 119.2 and 151.6 cm was recorded at 25, 50, 75 and 100 DAS respectively under H_1. Similarly, the impact of crop geometric strategies on plant height was also found significant. The maximum plant height of 13, 59.2, 128.4 and 166.2 cm was recorded under C_4; while the minimum plant height of 10.4, 49.9, 121.9 and 156.3 cm was recorded under C_1 at the 25, 50, 75 and 100 DAS respectively. The interaction effect of hydrogel levels as well as crop geometric strategies was statistically significant. At 25 DAS, the maximum plant height of 15.4 cm was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule). On average the minimum plant height of 9.0 cm resulted under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). At 50 DAS, the effect of all treatments varied significantly. Overall, the maximum plant height of 67.5 cm was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule). The minimum plant height of 40.4 cm was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). At 75 DAS, all the 12 treatments have differed in their effect. The significantly highest plant height of 134.0 cm and the lowest of 114.9 cm were recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule) and H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm) respectively. The maximum plant height of 174.0 cm was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) at 100 DAS, while H_3C_3 i.e., hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule has shared partial parity with the H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule).

In the second year (2023) of study, the impact of hydrogel levels was found significant. The maximum plant height of 20.3, 79.8, 160.6 and 206.5 cm was recorded under H_3; while the minimum plant height of 13.7, 56.7, 136.5 and 178.1 cm was recorded under H_1 at the 25, 50, 75 and 100 DAS respectively. The effect of crop geometric strategies was statistically significant. The highest plant height of 18.7, 72, 152.1 and 198.7 cm resulted under C_4 followed by C_3, C_2 and C_1 at the 25, 50, 75 and 100 DAS respectively. While, the lowest plant height of 15.2, 64.7, 142.5 and 185.5 cm was recorded under C_1 at 25, 50, 75 and 100 DAS respectively. There was a significant interaction effect of hydrogel levels as well as crop geometric strategies was found. At the 25, 50, 75 and 100 DAS, the significantly highest plant height of 22.6, 82.9, 163.7 and 210.3 cm respectively resulted under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm), while the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) resulted in lowest plant height of 12.6, 52.8, 132.4 and 171.7 cm at 25, 50, 75 and 100 DAS respectively.

In the mean data, the hydrogel levels have shown a significant impact on the plant height., The maximum plant height of 17.2, 71.9, 146 and 188.9 cm at the 25, 50, 75 and 100 DAS respectively resulted under H_3, while the minimum plant height of 11.7, 51.1, 127.8 and 164.9 cm respectively resulted under H_1. The crop geometric strategies have significantly improved plant height. Among all crop geometric strategies, the maximum plant height of 15.8, 65.6, 140.2 and 182.5 cm at the 25, 50, 75 and 100 DAS respectively resulted under C_4. While the minimum plant height of 12.8, 57.3, 132.2 and 171.0 cm was recorded under C_1 at the 25, 50, 75 and 100 DAS respectively. The interaction effect of both factors was found significant. At all the growth intervals, the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) resulted in significantly highest plant height of 19.0, 75.2, 148.9 and 192.1 cm was recorded at the 25, 50, 75 and 100 DAS respectively. At 50 DAS, the effect of all the treatments differed significantly. On average, the lowest plant height of 10.8, 46.6, 123.7 and 160.1 cm at the 25, 50, 75 and 100 DAS respectively resulted under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).

Table. 4.1. Impact of different hydrogel levels and crop geometric strategies on the plant height (cm) of spring maize at 25, 50, 75 and 100 DAS.														
S. no	Factors		25 DAS			50 DAS			75 DAS			100 DAS		
			2022	2023	Mean	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
	Hydrogel levels													
1	H1	Without hydrogel application in soil	9.8	13.7	11.7	45.6	56.7	51.1	119.2	136.5	127.8	151.6	178.1	164.9
2	H2	With hydrogel application in the soil at 1.5 kg/ha	11.5	16.4	13.9	54.3	68.5	61.4	125.8	145.6	135.7	161.4	191.5	176.5
3	H3	With hydrogel application in the soil at 3 kg/ha	14.0	20.3	17.2	64.1	79.8	71.9	131.3	160.6	146.0	171.2	206.5	188.9
		CD (at p≤ 0.05)	0.215	0.217	0.121	0.518	0.714	0.602	0.591	0.928	0.458	1.542	1.2	1.3
		SEm (±)	0.053	0.054	0.030	0.129	0.177	0.149	0.147	0.230	0.114	0.383	0.291	0.315
	Crop geometric strategies													
1	C1	Normal spacing (70 × 25 cm)	10.4	15.2	12.8	49.9	64.7	57.3	121.9	142.5	132.2	156.3	185.5	171.0
2	C2	Paired-row spacing (55 - 85 × 25 cm)	11.1	16.2	13.6	53.5	66.7	60.1	124.8	146.4	135.6	160	189.2	174.6
3	C3	Normal spacing (70 × 25 cm) with seed capsule	12.6	17.3	14.9	56.0	69.8	62.9	126.78	149.3	138.0	162.9	194.8	178.9
4	C4	Paired-row spacing (55 - 85 × 25 cm) seed capsule	13.0	18.7	15.8	59.2	72.0	65.6	128.4	152.1	140.2	166.2	198.7	182.5
		CD (at p≤ 0.05)	0.258	0.152	0.165	0.626	0.520	0.432	0.486	0.569	0.385	1.2	0.881	0.728
		SEm (±)	0.086	0.051	0.055	0.209	0.174	0.144	0.162	0.190	0.129	0.399	0.294	0.344
		A x B	0.440	0.311	0.274	1.1	1.0	0.875	0.930	1.3	0.730	2.342	1.748	0.243

Table. 4.2. Impact of the interaction of different hydrogel levels and crop geometric strategies on the plant height (cm) of spring maize at 25 DAS.

Plant height (2022)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	9.0	9.9	12.1	10.4
	C_2	9.3	10.5	13.5	11.1
	C_3	10.1	12.8	14.8	12.6
	C_4	10.9	12.7	15.4	13.0
Mean		9.9	11.5	14.0	
		CD (at $p \leq 0.05$)	0.440		
		SEm (±)	0.107		

Plant height (2023)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	12.6	14.7	18.1	15.2
	C_2	13.0	16.0	19.4	16.2
	C_3	13.8	16.7	21.2	17.2
	C_4	15.3	18.1	22.6	18.7
Mean		13.7	16.4	20.3	
		CD (at $p \leq 0.05$)	0.311		
		SEm (±)	0.093		

Plant height (Mean)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	10.8	12.3	15.1	12.8
	C_2	11.2	13.3	16.5	13.6
	C_3	12.0	14.8	18.0	15.0
	C_4	13.1	15.4	19.0	15.9
Mean		11.8	13.9	17.2	
		CD (at $p \leq 0.05$)	0.274		
		SEm (±)	0.088		

Table. 4.3. Impact of the interaction of different hydrogel levels and crop geometric strategies on the plant height (cm) of spring maize at 50 DAS.

Plant height (2022)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	40.4	48.7	60.6	49.9
	C_2	43.8	53.7	62.9	53.5
	C_3	46.9	56.0	65.2	56.0
	C_4	51.2	58.8	67.5	59.2
Mean		45.6	54.3	64.1	
		CD (at p≤ 0.05)	1.1		
		SEm (±)	0.339		
Plant height (2023)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	52.8	63.9	77.5	64.7
	C_2	56.4	65.7	78.1	66.7
	C_3	58.0	70.9	80.6	69.8
	C_4	59.5	73.6	82.9	72.0
Mean		**56.7**	68.5	79.8	
		CD (at p≤ 0.05)	1.0		
		SEm (±)	0.315		
Plant height (Mean)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	46.6	48.7	69.1	57.3
	C_2	50.1	53.7	70.5	60.1
	C_3	52.5	56.0	72.9	62.9
	C_4	55.4	58.8	75.2	65.6
Mean		**51.1**	61.4	71.9	
		CD (at p≤ 0.05)	0.875		
		SEm (±)	0.263		

Table. 4.4. Impact of the interaction of different hydrogel levels and crop geometric strategies on the plant height (cm) of spring maize at 75 DAS.

Plant height (2022)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	114.9	123.5	127.2	121.9
	C_2	118.4	125.2	130.1	124.8
	C_3	121.1	126.1	133.2	126.8
	C_4	122.5	128.6	134.0	128.4
Mean		119.2	125.8	131.4	
		CD (at p≤ 0.05)	0.920		
		SEm (±)	0.284		
Plant height (2023)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	132.4	138.2	156.8	142.5
	C_2	135.5	144.0	159.6	146.4
	C_3	137.7	147.7	162.4	149.3
	C_4	140.3	152.4	163.7	152.1
Mean		136.5	145.6	160.6	
		CD (at p≤ 0.05)	1.3		
		SEm (±)	0.366		
Plant height (Mean)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	123.7	130.9	142.0	132.2
	C_2	127.0	134.6	145.3	135.6
	C_3	129.4	136.9	147.8	138.0
	C_4	131.4	140.5	148.9	140.2
Mean		127.8	135.7	146.0	
		CD (at p≤ 0.05)	0.730		
		SEm (±)	0.224		

Table. 4.5. Impact of the interaction of different hydrogel levels and crop geometric strategies on the plant height (cm) of spring maize at 100 DAS.

Plant height (2022)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	148.6	153.0	167.5	156.4
	C_2	149.4	159.9	170.8	160.1
	C_3	151.6	164.5	172.6	162.9
	C_4	156.7	168.1	174.0	166.2
Mean		151.6	161.4	171.2	
		CD (at p≤ 0.05)	2.3		
		SEm (±)	0.711		
Plant height (2023)		**Hydrogel levels**			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	171.7	183.0	202.0	185.6
	C_2	174.9	187.5	205.2	189.2
	C_3	180.7	195.3	208.4	194.8
	C_4	185.4	200.4	210.3	198.7
Mean		178.2	191.6	206.5	
		CD (at p≤ 0.05)	1.7		
		SEm (±)	0.528		
Plant height (Mean)		**Hydrogel levels**			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	160.1	168.0	184.7	170.9
	C_2	162.2	173.7	188.0	174.6
	C_3	166.2	179.9	190.5	178.9
	C_4	171.0	184.3	192.1	182.5
Mean		164.9	176.4	188.9	
		CD (at p≤ 0.05)	1.7		
		SEm (±)	0.482		

Plant height is the key parameter that defines the growth visually over a period of time. Both years have experienced contrast and varied weather conditions, particularly in the early cropping season. In the first year, there was a heat wave effect with peak summer temperatures. In the later year, the weather conditions were much more favourable for the spring maize with sufficient rainfall and optimal temperatures required for virtuous crop growth. The maximum AWT (average weekly temperature) during the week of sowing (9th SMW) was 17.1ºC and 27.4ºC; while the minimum AWT was 9.3ºC and 14ºC in 2022 and 2023 respectively. The optimal temperature required for maize germination is 25-28ºC **(Farooq *et al.,* 2008).** The adverse conditions in 2022, led to delayed germination. Due to the application of hydrogel, a better germination rate was obtained with the rise in the dose of the hydrogel. The addition of hydrogel **(Prisa & Guerrini, 2023; Jong *et al.,* 2024)** and humic acid **(Yang *et al.,* 2023)** in the seed capsule, enhanced the germination rate along with other favourable conditions in 2023. The germination rate and time difference in both years might have influenced the plant height at 25 DAS **(Thejesh *et al.,* 2024).** The low-temperature extremes could have weakened the seedlings and led to poor photosynthetic activity in 2022 **(Hussain *et al.,* 2019).** They eventually, made plants deficient in macronutrients by restrictive metabolite transport **(Liu *et al.,* 2016).** This could be possibly one of the reasons for poor plant height in 2022 when compared to the later year.

In 2022, the abrupt escalation of temperatures from the 12th SMW resulted in heat stress, that might have enhanced the content of abscisic acid (ABA), a growth inhibitor **(Rosmaina *et al.,* 2021).** The preeminent climb in the ABA levels as a part of the stress adaptive response of crop perhaps affected the plant height negatively in the case of control of hydrogel **(Li *et al.,* 2021; Aslam e*t al.,* 2022).** In the later year, the optimal weather conditions for crop growth could have hindered the stress buildup on the crop **(Salem *et al.,* 2023).** The maximum AWT exceeded 40ºC only twice (19th and 20th SMW) in 2023, while a constant maximum AWT of more than 40ºC was seen in 2022. The plant height was negatively impacted by the heat wave. The rise in the hydrogel dose was proportional to plant height **(Albalasmeh *et al.,* 2022; Radian *et al.,* 2022).** The hydrogel amendment in the soil might have enhanced the water-holding capacity and abridged moisture loss thereby making water more accessible to plants thus promoting growth **(Mohawesh & Durner, 2019;).** The contents in the seed capsule like biofertilizers, humic acid and neem powder perhaps showed their full potential in enhancing water retention, nutrient mobility and effective plant protection **(Pukalchik *et al.,* 2019).** The biofertilizers might have ascribed to the uninterrupted supply of nutrients like N, P and K by fixing atmospheric N and effective absorption of available N (Rhizobium, Azotobacter, Acetobacter), solubilizing P (Phosphate-Solubilizing Bacteria - PSB, Pseudomonas) and mobilizing K (Potassium-Solubilizing Bacteria - KSB) to plants across the cropping season and promoting root uptake while reducing nutrient losses through leaching and volatilization **(Thejesh *et al.,* 2020).** The higher plant height could have resulted from the increased auxin-producing ability due to the biofertilizers **(Bradacova *et al.,* 2020).** The findings are in accordance with those of **Meena *et al.* (2023); Eni Maftu'ah *et al.* (2023).** The co-adjuvant amalgamation of irrigation and crop geometric strategies might have prevented competition, stress and enhanced macronutrient availability, attributed to rapid cell division and enlargement. Thus, a progressive repercussion in plant height **(Alori *et al.,* 2019; Mtatia *et al.,* 2019; Kumar *et al.,* 2020).** Analogous outcomes were obtained by **Abubakar *et al.* (2019); Abdo *et al.* (2022).**

4.1.1.2. Number of leaves

The data on the influence of different hydrogel levels and crop geometry on the number of leaves of spring maize is depicted in tables 4.6- 4.10. In the first year (2022) of study, hydrogel levels significantly affected the leaf count at every growth stage. H_3 resulted in the maximum number of leaves of 7.1, 9.8, 15.8 and 14.0 at 25, 50, 75 and 100 DAS respectively. A minimum number of leaves of 3.9, 7.6, 14.1 and 12.2 were obtained by H_1 at the 25, 50, 75 and 100 DAS respectively. Similarly, the crop geometric strategies had a significant impact on leaf count. The maximum number of leaves of 6.5, 9.2, 15.5 and 13.7 were recorded under C_4; and the minimum number of leaves of 4.9, 8.0, 14.4 and 12.6 at 25, 50, 75 and 100 DAS respectively were recorded under C_1. There was a substantial influence of both factors on the leaf count at 75 and 100 DAS. At 75 DAS, the maximum number of leaves of 16.1 resulted under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) and a minimum of 13.3 by H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). The maximum number of leaves of 14.3 resulted under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) and a minimum of 11.4 under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) at 100 DAS. Treatments H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule) and H_3C_2 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)) shared statistical parity with the H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) at 75 and 100 DAS.

During the second year (2023) of study, hydrogel levels substantially improved the leaf count at every growth stage. Among the hydrogel levels, the H_3 has resulted in the highest leaf count of 7.7, 10.4, 16.2 and 14.9 at 25, 50, 75 and 100 DAS respectively. While the least leaf count of 4.2, 7.9, 14.4 and 13.1 resulted under H_1 at the 25, 50, 75 and 100 DAS respectively.

A substantial enhancement of leaf count was recorded under the crop geometric strategies. Among the crop geometric strategies, the C_4 has resulted in maximum no. of leaves of 6.5, 9.7, 16.0 and 14.6, while the minimum no. of leaves of 5.0, 8.6, 14.8 and 13.5 resulted under C_1 at 25, 50, 75 and 100 DAS respectively. The impact of the interaction of both factors was substantial on the leaf number at every growth stage. Overall, the maximum count of leaves of 8.6 and 11.2 was obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) at 25 and 50 DAS respectively, while the minimum count of leaves of 3.5 and 7.3 was obtained by H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) at 25 and 50 DAS respectively. At 75 DAS, the maximum no. of leaves of 16.6 was obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm), while H_1C_1 (Hydrogel 0 kg/ha + Normal spacing (70 × 25 cm)) resulted in the minimum of 13.8. At 100 DAS, the maximum no. of leaves of 15.1 were recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm), while a minimum of 12.6 were recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). The treatments H_2C_4 (hydrogel 1.5 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule), H_3C_2 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)) and H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with the seed capsule) shared statistical parity with the H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule).

Regarding the mean data, the impact of hydrogel levels on the leaf count was found significant at all the growth intervals. Among the hydrogel levels, the maximum number of leaves of 7.4, 10.1, 16.0 and 14.4 was recorded under H_3; while a minimum of 4.0, 7.7, 14.3 and 12.7 was recorded under H_1 at 25, 50, 75 and 100 DAS respectively. The crop geometric strategies have significantly increased the leaf number. Among the crop geometric strategies, the maximum number of leaves of 6.5, 9.5, 15.7 and 14.2 were recorded under C_4; whereas a minimum number of leaves of 5.0, 8.3, 14.6 and 13 were recorded under C_1 at 25, 50, 75 and 100 DAS respectively. At the 50, 75 and 100 DAS, a significant interaction effect of both factors was recorded in the improvement of leaf count. At the 50 DAS, a significantly maximum number of leaves of 10.8 was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) and a minimum of 7.3 under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). The highest leaf count of 16.3 was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) and the lowest leaf count of leaves of 13.6 was recorded under H_1C_1 (Hydrogel 0 kg/ha + Normal spacing (70 × 25 cm)) at 75 DAS. The highest number of leaves of 14.7 was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) and the highest number of leaves of 12.0 was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) at 100 DAS. However, the treatments H_3C_3 (hydrogel 3 kg/ha +

Table. 4.6. Influence of different hydrogel levels and crop geometric strategies on the number of leaves of spring maize at 25, 50 75 and 100 DAS.														
S. no	Factors		25 DAS			50 DAS			75 DAS			100 DAS		
			2022	2023	Mean	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
	Hydrogel levels													
1	H_1	Without hydrogel application in soil	3.9	4.2	4.0	7.6	7.9	7.7	14.1	14.4	14.3	12.2	13.1	12.7
2	H_2	With hydrogel application in the soil at 1.5 kg/ha	6.0	5.4	5.7	8.6	9.2	8.9	15.0	15.4	15.2	13.2	14.0	13.6
3	H_3	With hydrogel application in the soil at 3 kg/ha	7.1	7.7	7.4	9.8	10.4	10.1	15.8	16.2	16.0	14.0	14.9	14.4
		CD (at p≤ 0.05)	0.255	0.233	0.101	0.281	0.250	0.204	0.313	0.209	0.249	0.189	0.297	0.230
		SEm (±)	0.063	0.058	0.025	0.070	0.062	0.051	0.078	0.062	0.062	0.047	0.074	0.057
		Crop geometric strategies												
1	C_1	Normal spacing (70 × 25 cm)	4.9	5.0	5.0	8.0	8.6	8.3	14.4	14.8	14.6	12.6	13.5	13.0
2	C_2	Paired-row spacing (55 - 85 × 25 cm)	5.4	5.6	5.5	8.5	9.0	8.7	14.8	15.1	14.9	12.9	13.8	13.4
3	C_3	Normal spacing (70 × 25 cm) with seed capsule	5.8	5.8	5.8	8.9	9.3	9.1	15.1	15.4	15.3	13.3	14.1	13.7
4	C_4	Paired-row spacing (55 - 85 × 25 cm) seed capsule	6.5	6.5	6.5	9.2	9.7	9.5	15.5	16.0	15.7	13.7	14.6	14.2
		CD (at p≤ 0.05)	0.193	0.201	0.154	0.196	0.205	0.147	0.215	0.182	0.133	0.243	0.204	0.174
		SEm (±)	0.065	0.067	0.052	0.065	0.068	0.049	0.072	0.061	0.045	0.081	0.068	0.058
		A x B	NS	0.377	NS	NS	0.392	0.298	0.444	0.340	0.316	0.408	0.422	0.344

Table. 4.7. Impact of the interaction of different hydrogel levels and crop geometric strategies on the number of leaves of spring maize at 25 DAS.

Number of leaves (2022)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	3.1	5.1	6.5	4.9
	C_2	3.6	5.7	7.0	5.4
	C_3	3.9	6.2	7.2	5.8
	C_4	4.9	6.9	7.8	6.5
Mean		3.9	6.0	7.1	
		CD (at p≤ 0.05)	NS		
		SEm (±)	0.116		
Number of leaves (2023)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	3.5	4.9	6.7	5.0
	C_2	4.0	5.2	7.5	5.6
	C_3	4.1	5.5	8.0	5.9
	C_4	5.0	6.1	8.6	6.5
Mean		4.2	5.4	7.7	
		CD (at p≤ 0.05)	0.337		
		SEm (±)	0.116		
Number of leaves (Mean)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	3.3	5.0	6.6	5.0
	C_2	3.8	5.4	7.3	5.5
	C_3	4.0	5.9	7.6	5.8
	C_4	5.0	6.5	8.2	6.5
Mean		4.0	5.7	7.4	
		CD (at p≤ 0.05)	NS		
		SEm (±)	0.081		

Table. 4.8. Impact of the interaction of different hydrogel levels and crop geometric strategies on the number of leaves of spring maize at 50 DAS.

Number of leaves (2022)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	7.2	7.9	9.0	8.0
	C_2	7.4	8.4	9.6	8.4
	C_3	7.7	8.9	10.2	8.9
	C_4	8.1	9.2	10.4	9.2
Mean		7.6	8.6	9.8	
		CD (at p≤ 0.05)	NS		
		SEm (±)	0.120		

Number of leaves (2023)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	7.3	8.8	9.8	8.6
	C_2	7.8	9.2	10.0	9.0
	C_3	8.1	9.1	10.7	9.3
	C_4	8.3	9.7	11.2	9.7
Mean		7.9	9.2	10.4	
		CD (at p≤ 0.05)	0.392		
		SEm (±)	0.120		

Number of leaves (Mean)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	7.3	8.3	9.4	8.3
	C_2	7.6	8.8	9.8	8.7
	C_3	7.9	9.0	10.4	9.1
	C_4	8.2	9.4	10.8	9.5
Mean		7.7	8.9	10.1	
		CD (at p≤ 0.05)	0.298		
		SEm (±)	0.09		

Table. 4.9. Impact of the interaction of different hydrogel levels and crop geometric strategies on the number of leaves of spring maize at 75 DAS.

Number of leaves (2022)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	13.3	14.6	15.4	14.4
	C_2	13.8	14.8	15.8	14.8
	C_3	14.4	15.1	15.9	15.1
	C_4	14.9	15.6	16.1	15.5
Mean		14.1	15.0	15.8	
		CD (at p≤ 0.05)	0.444		
		SEm (±)	0.133		

Number of leaves (2023)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	13.8	15.0	15.8	14.8
	C_2	14.0	15.1	16.1	15.1
	C_3	14.6	15.4	16.3	15.4
	C_4	15.3	16.0	16.6	16.0
Mean		14.4	15.4	16.2	
		CD (at p≤ 0.05)	0.340		
		SEm (±)	0.105		

Number of leaves (Mean)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	13.6	14.8	15.6	14.6
	C_2	13.9	14.9	15.9	14.9
	C_3	14.5	15.3	16.1	15.3
	C_4	15.1	15.8	16.3	15.7
Mean		14.3	15.2	16.0	
		CD (at p≤ 0.05)	0.316		
		SEm (±)	0.091		

Table. 4.10. Impact of the interaction of different hydrogel levels and crop geometric strategies on the number of leaves of spring maize at 100 DAS.

Number of leaves (2022)		Hydrogel levels			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	11.4	12.8	13.6	12.6
	C_2	11.9	12.9	14.0	12.9
	C_3	12.7	13.2	14.1	13.3
	C_4	13.0	13.9	14.3	13.7
Mean		12.2	13.2	14.0	
		CD (at p≤ 0.05)	0.408		
		SEm (±)	0.130		
Number of leaves (2023)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	12.6	13.6	14.6	13.6
	C_2	12.9	13.8	14.9	13.8
	C_3	13.2	14.1	15.0	14.1
	C_4	13.9	14.8	15.1	14.6
Mean		13.1	14.0	14.9	
		CD (at p≤ 0.05)	0.422		
		SEm (±)	0.126		
Number of leaves (Mean)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	12.0	13.2	14.1	13.1
	C_2	12.4	13.3	14.4	13.4
	C_3	12.9	13.7	14.6	13.7
	C_4	13.4	14.3	14.7	14.2
Mean		12.7	13.6	14.4	
		CD (at p≤ 0.05)	0.344		
		SEm (±)	0.104		

normal spacing (70 × 25 cm) with seed capsule) and H_3C_2 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)) shared statistical parity with the H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule).

The leaf number is a vital attribute as the leaves are the manufacturing unit of food through photosynthesis. More the leaf count, the more will be the leaf area and ultimately the photosynthetic activity. It has been evident that the employment of hydrogel has shown a significant improvement in the leaf count. These findings are in accordance with that of **Sasmal & Patra (2022); Chikarango *et al.* (2021); Hafiz-Afham *et al.* (2023).** The increment in the leaf count might be due to the superior accretion of photosynthates endorsed the plant growth. **(Verma *et al.,* 2018).** Generally, maize leaf growth rises when temperatures range from 10-35^{0}C, but when the temperature exceeds 35^{0}C, it results in a decline in the leaf growth **(Hussain *et al.,* 2006).** The persistent maximum AWT of more than 40^{0}C might have resulted in a deprived leaf count in 2022. The paired row spacing could have permitted improved light capture by plants, thereby enhanced leaf count and eventually the photosynthetic activity **(Qodliyati & Nyoto, 2018; Bernhard & Below, 2020).** The combined effect of hydrogel, spacing and seed capsule demonstrated their role in the persuasive rise in the leaf number which might be because of the expeditious cell division, expansion and elongation **(Kumar *et al.,* 2020).** The constant nutrient holding and mobilization competence of hydrogel as well as biofertilizers along with paired row spacing might have reduced the competition and enhanced nutrient availability to the plant consequently amplified the leaf count in maize **(Rokhminarsi and Utami, 2019; Radian *et al.,* 2022).**

4.1.1.3. Stem girth (cm):

The data on the impact of different hydrogel levels and crop geometric strategies on the stem girth (cm) of spring maize is depicted in tables (4.11- 4.15). In the first year (2022) of study, hydrogel levels significantly increased the stem girth at all the growth stages. A wider stem girth of 3.1, 5.6, 7.9 and 9.5 cm was obtained by H_3 at 25, 50, 75 and 100 DAS, respectively. While, the shorter stem girth of 1.7, 4.5, 6.6 and 7.7 cm was obtained by H_1 at the 25, 50, 75 and 100 DAS, respectively. The effect of crop geometric strategies was also found significant. The crop geometric strategies differed at 25, 75 and 100 DAS, whereas at 50 DAS the C_2 and C_3 were found at par with each other. The maximum stem girth of 2.7, 5.2, 7.5 and 8.9 cm at the 25, 50, 75 and 100 DAS respectively was recorded under C_4. While the minimum stem girth of 2, 4.7, 6.9 and 8.1 cm was recorded under C_1 at 25, 50, 75 and 100 DAS respectively. A substantial influence of the interaction of different hydrogel levels and crop geometric strategies on improving the stem girth of spring maize was reported. At 25 DAS, the maximum stem girth of 3.4 cm was obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule), while the minimum girth of 1.6 cm under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 x 25 cm) with seed capsule) has shared statistical parity with the H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule). At 50, 75 and 100 DAS, the significantly wider stem girth of 5.9, 8.1 and 10.0 cm respectively was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule, while the narrow girth of 4.3, 6.1 and 7.5 cm was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) at 50, 75 and 100 DAS respectively.

In the second year (2023) of study, a significant effect of hydrogel levels on the stem girth was found. Among the hydrogel levels, the wider stem girth of 3.6, 6.6, 8.5 and 10.3 cm was obtained by H_3; while the narrow stem girth of 2.7, 4.7, 7.0 and 8.6 cm was obtained by H_1 at 25, 50, 75 and 100 DAS respectively. The crop geometric strategies had a significant effect on the enhancement of the stem girth. Among the crop geometric strategies, the highest stem girth of 3.3, 5.9, 8.0 and 9.7 cm was obtained by C_4; while, the lowest stem girth of 3.0, 5.2, 7.4 and 9 cm was obtained by C_1 at 25, 50, 75 and 100 DAS respectively. The interaction impact of both factors was statistically significant. The wider stem girth of 3.7 cm was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule, while the narrow girth of 2.4 cm was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) at 25 DAS. The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 ×25 cm) with seed capsule) shared partial parity with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule). At 50 DAS, the wider stem girth of 6.9 cm was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule. The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule) was found statistically at par with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule). At 75 and 100 DAS, a significantly wider stem girth of 8.9 and 10.8 cm respectively was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule. While the narrow girth of 6.8 and 8.4 cm was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) at 75 and 100 DAS respectively.

Regarding the mean data, the impact of hydrogel levels on the stem girth was found substantial. Among the hydrogel levels, the maximum stem girth of 3.3, 6.1, 8.2 and 9.9 cm was recorded under H_3, while minimum stem girth of 2.1, 4.6, 6.8 and 8.2 cm was recorded under H_1 at 25, 50, 75 and 100 DAS respectively. The crop geometric strategies have significantly affected the stem girth. Among the crop geometric strategies, the wider stem girth of 3.0, 5.6, 8 and 9.3 cm was recorded under H_3, while the narrow stem girth of 2.5, 5.0, 7.1 and 8.6 cm was recorded under C_1 at 25, 50, 75 and 100 DAS respectively. A substantial influence of the interaction of both factors in augmenting stem girth. At 25 DAS, the maximum stem girth of 3.5 cm and the minimum stem girth of 2.0 cm were obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule and H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) respectively. The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) has shared statistical parity with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule). At 50 DAS, a significantly wider stem girth of 5.7 cm was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule and a narrow stem girth of 6.4 cm was recorded under H_1C_1 (Hydrogel 0 kg/ha + Normal spacing (70 × 25 cm)). At 75 DAS, the significant maximum stem girth of 8.5 cm was recorded under treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule, while the minimum stem girth of 6.4 was recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). At 100 DAS, a significantly wider stem girth of 10.4 cm was recorded under the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule, whereas the narrow stem girth of 8.0 cm was obtained by the H_3C_4 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm) with seed capsule.

4.1.1.4. Stem diameter (cm)

The data on the impact of different hydrogel levels and crop geometric strategies on the stem diameter (cm) of spring maize is depicted in tables (4.16- 4.20). In the first year (2022) of study, hydrogel levels significantly increased the stem diameter at all the growth stages. A wider stem diameter of 0.98,1.8, 2.5 and 3 cm was obtained by H_3 at 25, 50, 75 and 100 DAS, respectively. While, the shorter stem diameter of 0.56, 1.4, 2.1 and 2.5 cm was obtained by H1 at the 25, 50, 75 and 100 DAS, respectively. The influence of crop geometric strategies was also found significant. The crop geometric strategies differed at 25, 75 and 100 DAS, whereas at 50 DAS the C_2 and C_3 were found at par with each other. The maximum stem diameter of 0.87, 1.7, 2.4 and 2.8 cm at the 25, 50, 75 and 100 DAS respectively was recorded under C_4. While minimum stem diameter of 0.63, 1.5,2.2 and 2.6 cm was recorded under C_1 at 25, 50, 75 and 100 DAS respectively. A substantial influence of the interaction of different hydrogel levels and crop geometric strategies on improving the stem diameter of spring maize was reported. At 25 DAS, the maximum stem diameter of 1.08 cm was obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule), while the minimum diameter of 0.50 cm under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 x 25 cm) with seed capsule) has shared statistical parity with the H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule). At 50, 75 and 100 DAS, the significantly wider stem diameter of 1.9, 2.6 and 3.1 cm respectively was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule), while the narrow diameter of 1.4, 2.0 and 2.4 cm was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) at 50, 75 and 100 DAS respectively.

In the second year (2023) of study, a significant effect of hydrogel levels on the stem diameter was found. Among the hydrogel levels, the wider stem diameter of 1.15, 2.1, 2.7 and 3.3 cm was obtained by H_3; while the narrow stem diameter of 0.85, 1.5, 2.2 and 2.8 cm was obtained by H_1 at 25, 50, 75 and 100 DAS respectively. The crop geometric strategies had a significant effect on the enhancement of the stem diameter. Among the crop geometric strategies, the highest stem diameter of 1.07, 1.9, 2.6 and 3.1 cm was obtained by C_4; while, the lowest stem diameter of 0.95, 1.7, 2.3 and 2.9 cm was obtained by C_1 at 25, 50, 75 and 100 DAS respectively. The interaction impact of both factors was statistically significant. The wider stem diameter of 1.18 cm was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule), while the narrow diameter of 0.77 cm was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) at 25 DAS. The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 ×25 cm) with seed capsule) shared partial parity with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule). At 50 DAS, the wider stem diameter of 2.2 cm was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule. The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule) was found statistically at par with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule. At 75 and 100 DAS, a significantly wider stem diameter of 2.8 and 3.4 cm respectively was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule). While the narrow diameter of 2.2 and 2.7 cm was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) at 75 and 100 DAS respectively.

Regarding the mean data, the impact of hydrogel levels on the stem diameter was found substantial. Among the hydrogel levels, the maximum stem diameter of 1.07, 1.9, 2.6 and 3.2cm was recorded under H_3, while minimum stem diameter of 0.71, 1.5, 2.2 and 2.6 cm was recorded under H_1 at 25, 50, 75 and 100 DAS respectively. The crop geometric strategies have significantly affected the stem diameter. Among the crop geometric strategies, the wider stem diameter of 0.97, 1.8, 2.5 and 3.0 cm was recorded under H_3, while the narrow stem diameter of 0.79, 1.6, 2.3 and 2.7 cm was recorded under C_1 at 25, 50, 75 and 100 DAS respectively. A

Table. 4.11. Influence of different hydrogel levels and crop geometric strategies on the stem girth (cm) of spring maize at 25, 50, 75 and 100 DAS.

S. no	Factors		25 DAS			50 DAS			75 DAS			100 DAS		
			2022	2023	Mean	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
	Hydrogel levels													
1	H_1	Without hydrogel application in soil	1.7	2.7	2.1	4.5	4.7	4.6	6.6	7.0	6.8	7.7	8.6	8.2
2	H_2	With hydrogel application in the soil at 1.5 kg/ha	2.3	3.2	2.8	4.8	5.5	5.1	7.1	7.6	7.4	8.3	9.2	8.8
3	H_3	With hydrogel application in the soil at 3 kg/ha	3.1	3.6	3.3	5.6	6.6	6.1	7.9	8.5	8.2	9.5	10.3	9.9
		CD (at p≤ 0.05)	0.093	0.035	0.030	0.092	0.083	0.061	0.121	0.099	0.044	0.107	0.119	0.089
		SEm (±)	0.023	0.009	0.007	0.023	0.021	0.015	0.030	0.025	0.011	0.026	0.030	0.022
		Crop geometric strategies												
1	C_1	Normal spacing (70 × 25 cm)	2.0	3.0	2.5	4.7	5.2	5.0	6.9	7.4	7.1	8.1	9.0	8.6
2	C_2	Paired-row spacing (55 - 85 × 25 cm)	2.3	3.1	2.7	4.9	5.4	5.2	7.1	7.7	7.4	8.4	9.4	8.9
3	C_3	Normal spacing (70 × 25 cm) with seed capsule	2.5	3.2	2.9	4.9	5.8	5.4	7.2	7.8	7.5	8.6	9.5	9.0
4	C_4	Paired-row spacing (55 - 85 × 25 cm) seed capsule	2.7	3.3	3.0	5.2	5.9	5.6	7.5	8.0	7.8	8.9	9.7	9.3
		CD (at p≤ 0.05)	0.090	0.031	0.048	0.073	0.064	0.039	0.072	0.053	0.046	0.098	0.082	0.076
		SEm (±)	0.030	0.010	0.016	0.024	0.021	0.013	0.024	0.018	0.016	0.033	0.028	0.025
		A x B	0.163	0.058	0.077	0.142	0.126	0.083	0.161	0.125	0.082	0.180	0.170	0.143

Table. 4.12. Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem girth of spring maize at 25 DAS.

Stem girth (2022)		Hydrogel levels			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	1.6	1.7	2.6	2.0
	C_2	1.6	2.1	3.0	2.3
	C_3	1.9	2.3	3.2	2.5
	C_4	2.0	2.9	3.4	2.7
Mean		1.7	2.3	3.1	
		CD (at p≤ 0.05)	0.163		
		SEm (±)	0.051		
Stem girth (2023)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	2.4	3.1	3.5	3.0
	C_2	2.6	3.2	3.6	3.1
	C_3	2.8	3.3	3.7	3.2
	C_4	2.9	3.4	3.7	3.3
Mean		2.7	3.2	3.6	
		CD (at p≤ 0.05)	0.058		
		SEm (±)	0.018		
Stem girth (Mean)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	2.0	2.4	3.1	2.5
	C_2	2.1	2.7	3.3	2.7
	C_3	2.3	2.8	3.5	2.9
	C_4	2.4	3.2	3.5	3.0
Mean		2.2	2.8	3.3	
		CD (at p≤ 0.05)	0.077		
		SEm (±)	0.025		

Table. 4.13. Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem girth of spring maize at 50 DAS.

Stem girth (2022)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	4.3	4.6	5.3	4.7
	C_2	4.4	4.9	5.6	5.0
	C_3	4.5	4.5	5.7	4.9
	C_4	4.8	5.0	5.9	5.2
Mean		4.5	4.8	5.6	
		CD (at $p \leq 0.05$)	0.142		
		SEm (±)	0.043		

Stem girth (2023)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	4.3	5.1	6.1	5.2
	C_2	4.5	5.3	6.7	5.4
	C_3	4.9	5.6	6.9	5.8
	C_4	4.8	5.9	6.9	5.9
Mean		4.7	5.5	6.6	
		CD (at $p \leq 0.05$)	0.126		
		SEm (±)	0.038		

Stem girth (Mean)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	4.3	4.9	5.7	5.0
	C_2	4.5	5.1	6.2	5.2
	C_3	4.7	5.1	6.3	5.4
	C_4	4.8	5.5	6.4	5.6
Mean		4.6	5.2	6.1	
		CD (at $p \leq 0.05$)	0.077		
		SEm (±)	0.025		

Table. 4.14. Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem girth of spring maize at 75 DAS.

Stem girth (2022)		Hydrogel levels			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	6.1	6.9	7.6	6.9
	C_2	6.4	7.0	7.9	7.1
	C_3	6.7	7.1	8	7.3
	C_4	7.1	7.4	8.1	7.5
Mean		6.6	7.2	7.9	
		CD (at p≤ 0.05)	0.161		
		SEm (±)	0.047		

Stem girth (2023)		Hydrogel levels			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	6.8	7.2	8.1	7.4
	C_2	6.9	7.6	8.5	7.7
	C_3	7.1	7.7	8.7	7.8
	C_4	7.2	7.9	8.9	8.0
Mean		7.0	7.6	8.5	
		CD (at p≤ 0.05)	0.125		
		SEm (±)	0.036		

Stem girth (Mean)		Hydrogel levels			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	6.4	7.0	7.9	7.1
	C_2	6.6	7.3	8.2	7.4
	C_3	6.9	7.4	8.3	7.5
	C_4	7.2	7.7	8.5	7.8
Mean		6.8	7.4	8.2	
		CD (at p≤ 0.05)	0.082		
		SEm (±)	0.026		

Table. 4.15. Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem girth of spring maize at 100 DAS.

Stem girth (2022)		Hydrogel levels			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	7.5	7.9	9.0	9.1
	C_2	7.6	8.3	9.2	8.4
	C_3	7.7	8.4	9.7	8.6
	C_4	8.0	8.6	10	8.8
Mean		7.7	8.3	9.5	
		CD (at p≤ 0.05)	0.180		
		SEm (±)	0.056		
Stem girth (2023)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	8.4	8.9	9.8	9.0
	C_2	8.6	9.3	10.2	9.4
	C_3	8.6	9.4	10.4	9.5
	C_4	8.9	9.5	10.8	9.7
Mean		8.6	9.3	10.3	
		CD (at p≤ 0.05)	0.170		
		SEm (±)	0.051		
Stem girth (Mean)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	8.0	8.4	9.4	8.6
	C_2	8.1	8.8	9.7	8.8
	C_3	8.1	8.9	10.1	9.0
	C_4	8.4	9.0	10.4	9.3
Mean		8.2	8.8	9.9	
		CD (at p≤ 0.05)	0.143		
		SEm (±)	0.044		

Table. 4.16. Influence of different hydrogel levels and crop geometric strategies on the stem diameter (cm) of spring maize at 25, 50, 75 and 100 DAS.														
S. no		**Factors**	**25 DAS**			**50 DAS**			**75 DAS**			**100 DAS**		
			2022	**2023**	**Mean**	**2022**	**2023**	**Mean**	**2022**	**2023**	**Mean**	**2022**	**2023**	**Mean**
		Hydrogel levels												
1	H_1	Without hydrogel application in soil	0.56	0.85	0.71	1.4	1.5	1.5	2.1	2.2	2.2	2.5	2.8	2.6
2	H_2	With hydrogel application in the soil at 1.5 kg/ha	0.73	1.03	0.88	1.5	1.7	1.6	2.3	2.4	2.3	2.6	2.9	2.8
3	H_3	With hydrogel application in the soil at 3 kg/ha	0.98	1.15	1.07	1.8	2.1	1.9	2.5	2.7	2.6	3.0	3.3	3.2
		CD (at $p \leq 0.05$)	0.030	0.011	0.010	0.029	0.027	0.020	0.039	0.031	0.015	0.034	0.038	0.028
		SEm (±)	0.007	0.003	0.003	0.007	0.007	0.005	0.010	0.008	0.004	0.008	0.009	0.007
		Crop geometric strategies												
1	C_1	Normal spacing (70 × 25 cm)	0.63	0.95	0.79	1.5	1.7	1.6	2.2	2.3	2.3	2.6	2.9	2.7
2	C_2	Paired-row spacing (55 - 85 × 25 cm)	0.72	0.99	0.86	1.6	1.7	1.7	2.3	2.4	2.4	5.7	3.0	2.8
3	C_3	Normal spacing (70 × 25 cm) with seed capsule	0.79	1.03	0.91	1.6	1.9	1.7	2.3	2.5	2.4	2.7	3.0	2.9
4	C_4	Paired-row spacing (55 - 85 × 25 cm) seed capsule	0.87	1.07	0.97	1.7	1.9	1.8	2.4	2.6	2.5	2.8	3.1	3.0
		CD (at $p \leq 0.05$)	0.029	0.010	0.015	0.023	0.020	0.013	0.023	0.017	0.015	0.031	0.026	0.024
		SEm (±)	0.010	0.003	0.005	0.008	0.007	0.004	0.008	0.006	0.005	0.010	0.009	0.008
		A x B	0.052	0.018	0.025	0.045	0.040	0.027	0.052	0.040	0.026	0.057	0.054	0.045

Table. 4.17. Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem diameter of spring maize at 25 DAS.

Stem diameter (2022)		Hydrogel levels			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	0.50	0.56	0.84	0.63
	C_2	0.52	0.69	0.96	0.72
	C_3	0.59	0.75	1.04	0.79
	C_4	0.61	0.93	1.08	0.87
Mean		0.56	0.73	0.98	
		CD (at p≤ 0.05)	0.052		
		SEm (±)	0.016		

Stem diameter (2023)		Hydrogel levels			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	0.77	0.98	1.11	0.95
	C_2	0.82	1.01	1.15	0.99
	C_3	0.89	1.05	1.17	1.03
	C_4	0.94	1.08	1.18	1.07
Mean		0.85	1.03	1.15	1.01
		CD (at p≤ 0.05)	0.018		
		SEm (±)	0.006		

Stem diameter (Mean)		Hydrogel levels			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	0.64	0.77	0.98	0.79
	C_2	0.67	0.85	1.06	0.86
	C_3	0.74	0.90	1.10	0.91
	C_4	0.78	1.01	1.13	0.97
Mean		0.71	0.88	1.07	
		CD (at p≤ 0.05)	0.025		
		SEm (±)	0.008		

Table. 4.18. Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem diameter of spring maize at 50 DAS.

Stem diameter (2022)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	1.4	1.5	1.7	1.5
	C_2	1.4	1.5	1.8	1.6
	C_3	1.4	1.4	1.8	1.6
	C_4	1.5	1.6	1.9	1.7
Mean		1.4	1.5	1.8	1.6
		CD (at p≤ 0.05)	0.045		
		SEm (±)	0.014		

Stem diameter (2023)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	1.4	1.6	2.0	1.7
	C_2	1.4	1.7	2.1	1.7
	C_3	1.6	1.8	2.2	1.9
	C_4	1.5	1.9	2.2	1.9
Mean		1.5	1.7	2.1	1.8
		CD (at p≤ 0.05)	0.040		
		SEm (±)	0.012		

Stem diameter (Mean)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	1.4	1.6	1.8	1.6
	C_2	1.4	1.6	1.9	1.7
	C_3	1.5	1.6	2.0	1.7
	C_4	1.5	1.7	2.1	1.8
Mean		1.5	1.6	1.9	1.7
		CD (at p≤ 0.05)	0.027		
		SEm (±)	0.008		

Table. 4.19. Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem diameter of spring maize at 75 DAS.

Stem diameter (2022)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	2.0	2.2	2.4	2.2
	C_2	2.0	2.2	2.5	2.3
	C_3	2.1	2.3	2.5	2.3
	C_4	2.3	2.4	2.6	2.4
Mean		2.1	2.3	2.5	
		CD (at p≤ 0.05)	0.052		
		SEm (±)	0.015		
Stem diameter (2023)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	C_1	2.2	2.3	2.6	2.3
	C_2	2.2	2.4	2.7	2.4
	C_3	2.3	2.4	2.8	2.5
	C_4	2.3	2.5	2.8	2.6
Mean		2.2	2.4	2.7	2.5
		CD (at p≤ 0.05)	0.040		
		SEm (±)	0.011		
Stem diameter (Mean)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	C_1	2.1	2.2	2.5	2.3
	C_2	2.1	2.3	2.6	2.4
	C_3	2.2	2.4	2.6	2.4
	C_4	2.3	2.4	2.7	2.5
Mean		2.2	2.3	2.6	2.4
		CD (at p≤ 0.05)	0.026		
		SEm (±)	0.008		

Table. 4.20. Impact of the interaction of different hydrogel levels and crop geometric strategies on the stem diameter of spring maize at 100 DAS.

Stem diameter (2022)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	2.4	2.5	2.9	2.6
	C_2	2.4	2.7	2.7	2.7
	C_3	2.4	2.7	2.7	2.7
	C_4	2.5	2.7	3.1	2.8
Mean		2.5	2.6	3.2	2.7
		CD (at p≤ 0.05)	0.057		
		SEm (±)	0.018		

Stem diameter (2023)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	2.7	2.8	3.1	2.9
	C_2	2.7	3.0	3.3	3.0
	C_3	2.7	3.0	3.3	3.0
	C_4	2.8	3.0	3.4	3.1
Mean		2.8	2.9	3.3	3.0
		CD (at p≤ 0.05)	0.054		
		SEm (±)	0.016		

Stem diameter (Mean)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	2.5	2.7	3.0	2.7
	C_2	2.6	2.8	3.1	2.8
	C_3	2.6	2.8	3.2	2.9
	C_4	2.7	2.9	3.3	3.0
Mean		2.6	2.8	3.2	2.9
		CD (at p≤ 0.05)	0.045		
		SEm (±)	0.014		

substantial influence of the interaction of both factors in augmenting stem diameter. At 25 DAS, the highest stem diameter of 1.13 cm and the lowest stem diameter of 0.64 cm were obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule) and H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) respectively. The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule) has shared statistical parity with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule). At 50 DAS, a significantly wider stem diameter of 2.1 cm was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule) and a narrow stem diameter of 1.4 cm was recorded under H_1C_1 (Hydrogel 0 kg/ha + Normal spacing (70 × 25 cm)). At 75 DAS, the significant maximum stem diameter of 2.7 cm was recorded under treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule), while the minimum stem diameter of 2.1 was recorded under treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). At 100 DAS, a significantly wider stem diameter of 3.3 cm was recorded under the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule), whereas the narrow stem diameter of 2.5 cm was obtained by the H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).

Stem girth and diameter is an imperative parameter that indicates the thickness at the base of the stem and key component of the agronomic yield of the crop. The stem girth and diameter has substantially enhanced with the increase in the hydrogel doses. Thus, it shows that stem girth and diameter was substantially influenced and attained wider girth as well as diameter based on the hydrogel doses. This might have been due to an unceasing supply of moisture and nutrients and preventing stress development for the plant. The findings were similar to those of **Rios *et al.* (2021); Sasmal & Patra (2022); Albalasmeh *et al.* (2022), Radian *et al.* (2022); Salem *et al.* (2023).** Generally, stem girth and diameter show a substantially faster increment at the vegetative stage with the growing point nearer to the surface. The better plant development due to quicker root spreading and base elongation consequently resulted in better stem girth and diameter. The plant spacing is a crucial aspect because of the competition and the population is more inclined towards similar resources like nutrients, moisture and sunlight at the same time and amount**.** Paired row spacing might have curbed the competition between the population for resources and have effectively improved stem girth **(Bernhard & Below, 2020; Mahmud *et al.,* 2022).** As discussed in the section of plant height, the adverse weather conditions during the early growth stages in 2022 might have resulted in less stem girth and diameter, especially in the control treatment when compared to the later year (2023). The stem girth and diameter increment can be attributed because of enhanced nutrient availability through the use of hydrogel and biofertilizers which led to rapid cell enlargement thereby productive outcome on the stem girth and diameter **(Mtaita *et al.,* 2019).**

4.1.2. Yield parameters

4.1.2.1. Number of cobs per plant

The data on the influence of different hydrogel levels and crop geometry on the cob count per plant of spring maize is depicted in table 4.21. In the first year (2022) of study, hydrogel levels significantly increased the cob count per plant. Among the hydrogel levels, the maximum number (2.0) of cobs per plant was obtained by H_3. The H_2 shared statistical parity with H_3. While the minimum (1.2) cobs per plant were obtained by H_1. The effect of crop geometric strategies was found statistically significant. Among the crop geometric strategies, the highest cob count per plant of 1.9 was obtained by C_4, the C_3 shared statistical parity with C_4. While the lowest cob count per plant (1.5) was obtained by C_1. The impact of the interaction of both factors was found to be non-significant on number of cobs per plant.

In the second year (2023) of study, effect of hydrogel levels on the cob count per plant was found significant. Among the hydrogel levels, the highest cob count (2.1) per plant was recorded under H_3. While the lowest cob count (1.3) per plant was obtained by H_1. The significant impact of crop geometric strategies was found in the improvement of cob count per plant. Among the crop geometric strategies, the maximum (1.9) cob count per plant resulted under C_4, the C_3 shared statistical parity with C_4. While a minimum (1.5) cob count per plant was resulted under C_1. The interaction impact of both factors was statistically non-significant.

Regarding the mean data, the influence of hydrogel levels was found statistically significant on the cob count per plant. Among hydrogel levels, the highest (2.0) cob count per plant resulted under H_3, while the lowest (1.2) cob count per plant was obtained by H_1. The effect of crop geometric strategies on cob count per plant was found significant. Among the crop geometric strategies, the maximum (1.9) number of cobs was recorded under C_4. While the minimum number of cobs of 1.5 were recorded under C_1. The C_3 has shared statistical parity with C_4. A non-significant interaction effect was found between both factors.

The hydrogel polymer has a remarkable feature of nutrients as well as water holding and thereafter it slowly releases them throughout the late vegetative phase and early reproductive phase. This might perhaps be aided in the increment of the cobs per plant **(Jamwal *et al.,* 2023).** The paired-row spacing might have resulted in proper leaf canopy and better use of available resources by avoiding competition among the plants **(Abubakar *et al.,* 2019).** The contents of the seed capsule could have shown a progressive effect on the nutrient uptake and better accumulation of photosynthates and led to superior photoassimilates translocation from the source to sink that eventually resulted in increment of cobs per plant **(Kumar *et al.*, 2022).** Analogous outcomes were obtained by **Kumar *et al.* (2020); Roy *et al.* (2019); Thamatam & Mehera (2022).**

4.1.2.2. Length of cob (cm)

The data on the influence of various hydrogel levels and crop geometric strategies on the length of cob (cm) of spring maize is depicted in table 4.21. In the first year (2022) of the study, the impact of hydrogel levels was found statistically significant on the cob length. Among the hydrogel levels, there was a substantial increment of cob length with the rise in the hydrogel levels. The highest cob length of 19.4 cm was obtained by H_3, while the lowest cob length was obtained by H_1. A significant impact of crop geometric strategies on cob length was also found. Among the crop geometric strategies, the longest cob length of 18.2 cm was obtained by C_4, followed by C_3, C_2 and C_1. The shortest cob length of 16.8 cm was obtained by C_1. C_3 has shared statistical parity with C_4. A non-significant impact of the interaction of both factors in the increment of cob length was reported.

In the second year (2023) of study, impact of hydrogel levels on the cob length was found statistically significant. Among the hydrogel levels, the longest cob length of 20.2 cm was obtained by H_3. Whereas, the shortest cob length of 16.8 cm was obtained by H_1. The crop geometric strategies had a substantial impact on the improvement of the length of cob. Among the crop geometric strategies, the longest cob length of 19.0 cm was obtained by C_4, followed by C_3, C_2 and C_1. While the shortest cob length of 17.6 cm was obtained by C_1. C_3 has shared statistical parity with C_4. A non-significant interaction effect of both factors was found on the cob length.

In the mean data, the effect of hydrogel levels was found statistically significant. Among the hydrogel levels, H_3 resulted in a longest cob length of 19.8 cm, while a shortest cob length of 16.4 cm was obtained by H_1. The effect of crop geometric strategies on the cob length was also found statistically significant. Among the crop geometric strategies, the longest cob length of 18.6 cm resulted under C_4, whereas the shortest length of cob of 17.2 cm was obtained by C_1. C_3 has shared statistical parity with C_4. The interaction of both factors showed a non-significant effect in increasing the cob length.

The cob length has shown an increment with the increase in the dose of hydrogel. The polymer might have enhanced the moisture as well as nutrient preservation by avoiding the losses. At the same time, effective utilization of conserved resources with good plant-water relations resulted in better root-shoot development, leaf production as well as dry matter accumulation, which resonated in the betterment of cob length **(Shivakumar *et al.,* 2019).** A similar increment in the cob length with the hydrogel application was recorded by **Tyagi *et al.* (2018); Radian *et al.* (2022); Jamwal *et al.* (2023).** The positive impact of the biofertilizer consortium perhaps enhanced the nutrient accessibility in the rhizosphere, specifically the N availability at the late vegetative (**Sivamurugan *et al.,* 2018**). During this stage, maize experiences rapid vegetative growth and has a high N demand to support photosynthesis, enzyme production and protein synthesis. Nitrogen availability at this stage might have ensured higher energy production for reproductive development and supported the transition from vegetative to reproductive stages **(Tandon *et al.,* 2021; Thamatam & Mehera, 2022).** The mobilization of phosphorous and potassium in the soil and their availability could have promoted root growth as well as nutrient absorption which improved nutrient balance and plant resilience, thereby resulted in longer cobs **(Prayogo *et al.,* 2021; Abdo *et al.,* 2022).** These outcomes were similar with **Nand (2015); Kumar *et al.* (2017); Panchal *et al.* (2018).** The humic acid application might have increased the length of the cob up to an extent. These findings are supported by **Sagar *et al.* (2020).** The optimal amelioration of the rhizosphere with the nutrients, and their quick uptake by plants could have improved the photosynthetic activity. The effective utilization for cell growth at the reproductive phase might have been attributed to the longer length of cobs **(Sabur *et al.,* 2021).**

4.1.2.3. Cob girth (cm)

The data on the influence of different hydrogel levels and crop geometric strategies on the cob girth (cm) of spring maize is depicted in tables 4.21. In the first year (2022) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum cob girth of 15.2 cm was obtained by H_3, while the minimum cob girth of 12.6 cm was obtained by H_1. The impact of crop geometric strategies on the cob girth was also found statistically significant. Among the crop geometric strategies, the maximum cob girth of 14.4 cm was obtained by C_4. While the minimum cob girth of 13.2 cm was obtained by C_1. C_3 and C_2 have shared statistical parity with C_4. The impact of the interaction of both factors was also found statistically non-significant.

In the second year (2023) of the study, the hydrogel levels were found statistically significant in their effect. Among the hydrogel levels, the maximum cob girth of 15.8 cm was obtained by H_3, while the minimum cob girth of 13.1 cm was obtained by H_1. The effect of crop geometric strategies was also found statistically significant. Among the crop geometric strategies, the maximum cob girth of 15 cm was obtained by C_4, while the minimum cob girth of 13.7 cm was obtained by C_1. C_3 and C_2 have shared statistical parity with C_4. The statistically non-significant influence of the interaction of both factors was reported on cob girth.

In the mean data, effect of hydrogel levels was found statistically significant. Among hydrogel levels, the maximum cob girth of 15.5 cm was obtained by H_3, while the minimum cob girth of 12.9 cm was obtained by H_1. The crop geometric strategies were significantly effective in increasing the cob girth. Among the crop geometric strategies, the maximum cob girth of 14.7 cm was obtained by C_4, while the minimum cob girth of 13.4 cm was obtained by C_1. C_3 and C_2 have shared statistical parity with C_4. The non-significant interaction impact of both factors on cob girth was reported.

The cob girth increment was proportional to the increase in the hydrogel levels. The application of hydrogel might have enhanced the moisture and nutrient concentration in the rhizosphere, thereby good plant-water relations resulted in prompted nutrient uptake and translocation of assimilates which ultimately led to wider cob girth **(Rajavarthini & Kalayanasundaram, 2022; Radian *et al.,* 2022).** The increased nutrient accessibility by the content of the seed capsule might have promoted the proper grain formation and resulted in wider cob girth. Similarly, the paired row spacing might have enabled the better utilization of the resources and enhanced photosynthetic activity and translocation of photosynthates to reproductive parts **(Tandon *et al.,* 2021; Sabur *et al.,* 2021).** Similar outcomes were stated by **Sagar *et al.* (2020); Nand (2015); Panchal *et al.* (2018); Abdo *et al.* (2022).**

4.1.2.4. Weight of cob (with husk) (g)

The data regarding the influence of different hydrogel levels and crop geometric strategies on the weight of cob with husk (g) of spring maize is depicted in tables 4.21-4.22. In the first year (2022) of the study, the impact of hydrogel levels was statistically significant. Among the hydrogel levels, the highest cob weight with the husk of 205.4 g was obtained by H_3, while the lowest cob weight with the husk of 169.3 g was obtained by H_1. A significant effect of crop geometric strategies on the cob weight with the husk was found. Among the crop geometric strategies, the maximum cob weight with husk of 194.1 g was obtained by C_4, followed by C_3, C_2 and C_1. The minimum cob weight with the husk of 177.7 g was obtained by C_1. C_3 has shared statistical parity with C_4. A non-significant effect was found in the increment of cob weight by the integration of both factors.

In the second year (2023) of study, the influence of hydrogel levels was found statistically significant. Among all the hydrogel levels, the maximum cob weight of 221.5 g was obtained by H_3, while the minimum cob weight of 185.3 g was obtained by H_1. The crop geometric strategies have significantly affected the weight of the cob with husk. Among the crop geometric strategies, the maximum cob weight of 214.8 g was obtained by C_4. Whereas, the minimum cob weight of 193.6 g resulted under C_1. The impact of the interaction of both factors was found statistically significant. The treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) resulted in the maximum weight of cob with the husk of 225.8 g and the minimum weight of cob of 176.6 g was obtained by H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule), H_3C_2 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)), H_2C_4 (hydrogel 1.5 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) has shared statistical parity with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule).

In the mean data, the hydrogel levels have significantly affected the weight of cob with husk. Among the hydrogel levels, the maximum cob weight with husk of 213.4 g was recorded under H_3, whereas the minimum cob weight with husk of 177.4 g was recorded under H_1. Among the crop geometric strategies, the maximum cob weight with the husk of 204.5 g was recorded under C_4, while the minimum cob weight with the husk of 185.7 g was recorded under C_1. A non-significant interaction effect of both factors was found in the enhancement of cob weight.

4.1.2.5. Weight of cob (without the husk) (g)

The data regarding the impact of different hydrogel levels and crop geometric strategies on the weight of cob without husk (g) of spring maize is depicted in tables 4.21-4.22. In the first year (2022) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum cob weight of 161.6 g was obtained by H_3 followed by H_2 and H_1. While the minimum cob weight of 124.8 g was obtained by H_1. A significant impact of crop geometric strategies on weight of cob without the husk was found. Among the crop geometric strategies, the maximum cob weight of 153.8 g was obtained by C_4, while the minimum cob weight of 132.0 g was obtained by C_1. There was a non-significant impact on the improvement of the weight of the cob by integration of both factors.

In the second year (2023) of study, the effect of hydrogel levels was found statistically significant. Among all hydrogel levels, the highest cob weight of 169.4 g was obtained by H_3, while the lowest cob weight of 135.2 g was recorded under H_1. The crop geometric strategies were found statistically significant in their effect. Among the crop geometric strategies, the highest cob weight of 164.6 g was recorded under C_4, while the lowest cob weight of 143.3 g was recorded under C_1. The interaction of both factors was found statistically significant. The treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule)

Table. 4.21. Influence of different hydrogel levels and crop geometric strategies on the yield parameters of spring maize.

S. no	Factors	Number of cobs per plant			Length of cob (cm)			Cob girth (cm)			weight of cob with husk (g)			Weight of cob without husk (g)		
		2022	2023	Mean	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
Hydrogel levels																
1	H_1	1.2	1.3	1.2	16.0	16.8	16.4	12.6	13.1	12.9	169.3	185.3	177.4	124.8	135.2	130.0
2	H_2	1.7	1.7	1.7	16.8	17.6	17.2	13.8	14.3	14.0	184.9	205.3	195.1	143.4	155.3	149.3
3	H_3	2.0	2.1	2.0	19.4	20.2	19.8	15.2	15.8	15.5	205.4	221.5	213.4	161.6	169.4	165.5
CD (at $p \leq 0.05$)		0.433	0.153	0.194	1.2	1.5	1.3	1.0	1.2	1.1	7.8	9.2	7.1	5.7	9.5	5.5
SEm (±)		0.107	0.038	0.048	0.290	0.381	0.334	0.256	0.304	0.279	1.9	2.2	1.8	1.4	2.4	1.4
Crop geometric strategies																
1	C_1	1.5	1.5	1.5	16.8	17.6	17.2	13.2	13.7	13.4	177.7	193.6	185.7	132.0	143.3	137.6
2	C_2	1.6	1.6	1.6	17.0	17.8	17.4	13.8	14.2	14.0	184.8	201.7	193.2	141.4	150.5	145.9
3	C_3	1.8	1.7	1.8	17.6	18.3	18.0	14.2	14.7	14.5	189.5	206.0	197.8	146.0	154.7	150.3
4	C_4	1.9	1.9	1.9	18.2	19.0	18.6	14.4	15.0	14.7	194.1	214.8	204.5	153.8	164.6	159.3
CD (at $p \leq 0.05$)		0.275	0.156	0.111	0.940	1.04	1.0	0.8	0.93	0.86	5.4	4.6	3.9	5.0	5.1	4.0
SEm (±)		0.092	0.052	0.037	0.314	0.348	0.330	0.270	0.311	0.290	1.8	1.5	1.3	1.7	1.7	1.4
A x B		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	11.4	NS	NS	12.0	NS

has resulted in the highest cob weight of 175.2 g, whereas, the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) has resulted in the lowest cob weight of 125.9 g. The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule, H_3C_2 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)) and H_2C_4 (hydrogel 1.5 kg/ha + paired row spacing (55-85 × 25 cm)) with seed capsule was found statistically at par with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule).

In the mean data, the effect of hydrogel levels was found statistically significant. Among all the hydrogel levels, the maximum cob weight without husk of 165.5 g was recorded under H_3, while the minimum cob weight without husk of 130.0 g was recorded under H_1. The impact of crop geometric strategies was also found statistically significant. Among the crop-

Table. 4. 22. Interaction effect of different hydrogel levels and crop geometric strategies on the weight of cob with husk and without husk (g) of the spring maize.

Weight of cob with husk (2023)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Sub-plot	**C_1**	176.6	189.4	214.9	193.6
	C_2	180.5	203.4	221.3	201.7
	C_3	186.4	207.8	223.9	206.0
	C_4	198.1	220.6	225.8	214.8
Mean		185.4	205.3	221.5	
		CD (at p≤ 0.05)	11.4		
		SEm (±)	3.24		
Weight of cob without husk (2023)		**Crop geometric strategies**			
		H_1	**H_2**	**H_3**	**Mean**
Sub-plot	**C_1**	125.9	138.7	165.2	143.3
	C_2	131.3	152.7	167.4	150.5
	C_3	135.7	158.4	169.9	154.7
	C_4	147.2	171.3	175.2	164.8
Mean		**135.2**	155.2	169.4	
		CD (at p≤ 0.05)	12.0		
		SEm (±)	3.5		

geometric strategies, the highest cob weight of 159.3 g resulted under C_4, while the lowest cob weight without husk of 137.6 g resulted under C_1. There was a non-significant impact of both factors on the weight of cob without husk. The maize husk is the modification of leaves in the maize plant, which consists of chlorophyll that carries out photosynthesis. The additional photosynthetic activity along with the maize leaves can be beneficial for plants. The husk utilizes the light to break down water molecules to produce photosynthates that can be stored in cobs, during the reproductive phase **(Sabur *et al.,* 2021).** The amendment of hydrogel in the soil might have shown a progressive impact on the plant-water relations as the cob weight increased with the increase in the dose of hydrogel. The continuous supply of moisture in the root zone might have helped plants from the stressful conditions. The easy accessibility of moisture and nutrients for the plant could have been ascribed to the positive impact on the cob weight **(Radian *et al.,* 2022).** Sufficient water availability due to the hydrogel application might have aided in good plant growth and can perk up the photosynthesis rate and nutrient translocation into the plants. The partitioning of reproductive parts like cobs could have led to the highest cob weight **(Tenreiro *et al.,* 2020).** The effective uptake of macronutrients by the plants that are readily available due to the biofertilizer consortium might have condensed the tussle for resources as well as improved photosynthesis, efficient grain filling, energy transfer for kernel development and better starch accumulation ultimately enhanced the cob weight **(Prayogo *et al.,* 2021).** Similar findings were obtained by **Kumar *et al.* (2022).** The paired-row spacing might have enabled the abundant solar radiation, which resulted in the increment of chlorophyll content **(Patil *et al.,* 2018)** that could have enhanced the photosynthetic activity, thus finally resulted in the highest cob weight with the husk and without the husk **(Liu *et al.,* 2020).** In the case of cob weight with husk, the positive outcome might be due to amplified photosynthetic activity by the plant in addition to the husk which improved the accumulation of photosynthates in both husk and cob. In the case of cob weight without husk, because of the improved translocation of photosynthates to the cob resulted in proper grain filling which ensued in the heftier cobs. These findings are in line with **Panchal *et al.* (2018); Nand *et al.* (2015); Deshmukh *et al.* (2023).**

4.1.2.6. Number of rows per cob

The data pertaining to the impact of different hydrogel levels and crop geometric strategies on the number of rows per cob of spring maize is depicted in tables 4.23. In the first year (2022) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum number of rows of 12.6 was recorded under H_3. While the minimum number of rows of 10.4 was recorded under H_1. H_2 has shared statistical parity with

H_3. The impact of crop geometric strategies on the row count per cob was statistically significant. Among the crop geometric strategies, the maximum number of rows of 12.2 was recorded under C_4, while the minimum number of rows of 10.7 was recorded under C_1. C_2 and C_3 have shared statistical parity with C_4. The interaction effect of both factors was found statistically non-significant.

In the second year (2023) of the study, the impact of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum number of rows of 13.2 was recorded under H_3, while the minimum number of rows of 10.9 was recorded under H_1. H_2 has shared statistical parity with H_3. The crop geometric strategies were found statistically significant in their effect. Among all the crop geometric strategies, the highest number of rows of 12.9 was recorded under C_4. The lowest row count of 11.4 resulted under C_1. C_2 and C_3 have shared statistical parity with C_4. There was a non-significant effect of the integration of both factors on increasing the number of rows.

Regarding the mean data, the effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum number of rows of 12.9 per cob was recorded under H_3, whereas the minimum number of rows of 10.7 per cob was recorded under H_1. H_2 has shared statistical parity with H_3. The effect of crop geometric strategies was found statistically significant. Among the crop geometric strategies, C_4 has resulted in the maximum number of rows per cob of 12.6 followed by C_3, C_2 and C_1, while the minimum number of rows of 11.0 per cob resulted under C_1. C_2 and C_3 have shared statistical parity with C_4. A non-significant effect of both factors was found on the no. of rows per cob.

Hydrogel application resulted in an unceasing flow of moisture as well as nutrients which prevented stress development during the early reproductive stage **(Shivakumar *et al.,* 2019).** These outcomes are close to those of **Jamwal *et al.* (2023).** The microbial consortium of macronutrients perhaps helped in the enhanced macronutrient (NPK) availability. The sufficient availability of N supported ear initiation and row formation during the V_5-V_{12} stages increased the potential for more grain rows; while P availability ensured cell division in the ear shoot that led to better kernel row differentiation and K availability safeguarded strong ear development and prevented kernel abortion, which helped to sustain the number of grain rows. **(Tandon *et al.,* 2021).** The employment of humic acid along with the biofertilizers might be effective in the improvement of row count per cob **(Gou *et al.,* 2020).** The paired-row spacing aided in the better utilization of resources and integration with the hydrogel-enthused virtuous formation of plant assimilates resulted in superior row count per cob. The outcomes are in line with **Moghadam *et al.* (2014); Kumar & Shankarlingappa, 2017; Sagar *et al.* (2020); Thamtam & Mehera, 2022; Sabur *et al.* (2021); Reddy *et al.* (2023).**

4.1.2.7. No. of grains per row of cob

The data regarding the influence of different hydrogel levels and crop geometric strategies on the number of grains per row of cob of spring maize is depicted in tables 4.23. In the first year (2022) of the study, the effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest grain count of 30.6 per row was recorded under H_3, while the lowest grain count of 28.1 per row was recorded under H_1. H_2 has shared statistical parity with H_3. The crop geometric strategies were also significant in their effect. Among all the crop geometric strategies, the maximum no. of grains 30.1 per row was recorded under C_4, while the minimum no. of grains 28.6 per row was recorded under C_1. C_3 has shared statistical parity with C_4. The interaction effect of both factors was found to be statistically non-significant.

In the second year (2023) of study, the effect of hydrogel levels was found significant. Among the hydrogel levels, the maximum no. of grains of 32.9 per row were recorded under H_3, while the minimum no. of grains of 30.5 resulted under H_1. H_2 has shared statistical parity with H_3. The effect of crop geometric strategies on the grain count per row of cob was statistically significant. Among the crop geometric strategies, the maximum no. of grains (32.4) per row was recorded under C_4, while the minimum no. of grains (30.7) per row was recorded under C_1. C_2 and C_3 have shared statistical parity with C_4. The interaction of both the factors was found statistically non-significant.

Regarding the mean data, the hydrogel levels showed a substantial impact on the number of grains per row of cob. Among the hydrogel levels, the highest number of grains of 31.8 per row was recorded under H_3, while the lowest number of grains of 29.3 per row was recorded under H_1. H_2 has shared statistical parity with H_3. The effect of crop geometric strategies was found statistically significant. Among the crop geometric strategies, the maximum no. of grains 31.3 per row was recorded under C_4, while the minimum no. of grains 29.7 per row resulted under C_1. C_3 has shared statistical parity with C_4. There was a non-significant impact of the integration of both factors on the grain count per row.

The grain-filling stage is the crucial phase of the crop's lifecycle because this stage decides the yield of the crop. This phase is more prone to stress due to moisture, nutrients or extreme weather conditions. The hydrogel application might have aided in moisture stress mitigation and resulted in superior translocation of photoassimilates to sink **(Singh & Sandhu, 2020).** The microbial consortia might have enriched the soil with nutrients and enhanced the uptake. The adequate N availability prevented kernel abortion by maintaining leaf chlorophyll levels and ensuring consistent photosynthesis for grain development; while P availability which is crucial for pollen tube growth, fertilization, and embryo formation ensured proper grain initiation and improved kernel density per row and K availability helped in water regulation and stress tolerance, prevented kernel abortion and ensured fuller well-developed grains per row. **(Thamatam & Mehera, 2022).** Similar outcomes are reported by **Reddy *et al.* (2023); Ramesh & Chhabra (2023).** The usage of hydrogel, paired-row spacing and seed capsule might have augmented the moisture and nutrient accessibility, ultimately lead to higher grains per row of cob **(Sivamurgan *et al.,* 2018; Tandon *et al.,* 2021; Sagar *et al.,* 2020; Mahmud *et al*., 2022).**

4.1.2.8. Number of grains per cob

The data on the influence of different hydrogel levels and crop geometric strategies on the grain count per cob of spring maize is depicted in tables 4.23. In the first year (2022) of study, the effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum grain count per cob of 383.8 resulted under H_3, while the minimum grain count per cob of 293.2 resulted under H_1. The crop geometric strategies were significantly effective in the improvement of grains per cob. Among the crop geometric strategies, the highest grain count of 368.0 per cob was recorded under C_4, while the lowest grain count per cob of 305.1 was recorded under C_1. C_3 has shared statistical parity with C_4. The interaction effect of both factors was found statistically nonsignificant.

In the second year (2023) of study, the impact of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest no. of grains of 435.2 per cob was recorded under H_3, while the lowest no. of grains per cob of 333 was recorded under H_1. The crop geometric strategies were statistically significant in their effect. Among the crop geometric strategies, the highest no. of grains of 418.3 per cob was recorded under C_4, while the lowest no. of grains of 351.1 was recorded under C_1. C_3 has shared statistical parity with C_4. A non-significant interaction effect of both factors was found on increment of grain count per cob.

Regarding the mean data, a substantial influence of hydrogel levels on the grains per cob was found. Among hydrogel levels, the highest grain count per cob of 409.5 was obtained by H_3, whereas the lowest grain count per cob of 313.1 was obtained by H_1. The effect of crop geometric strategies was found statistically significant. Among the crop geometric strategies, the highest grain count of 393.1 per cob was obtained by C_4 followed by C_3, C_2 and C_1, while the lowest grain count of 328.1 per cob was obtained by C_1. C_3 was found to be statistically at par with C_4. A non-significant impact of the interaction of both factors on the no. of grains per cob of spring maize was reported.

The hydrogel employment possibly aided in the development of stress resistance and reduced nutrient leaching owing to its slow nutrient-releasing nature as per the crop requirement **(Rajavarthini & Kalayansundaram, 2022).** These outcomes are in accordance with those of **Jamwal *et al.* (2023); Shivakumar *et al.* (2019); Tyagi *et al.* (2015)**. The combined use of biofertilizers and humic acid might have enriched the root zone with positive aspects like nutrient mobility, uptake and root growth thereby curbed the stress development **(Canellas *et al.,* 2019)**. Analogous outcomes were stated by **Abdo *et al.* (2022); Thamatam & Mehera (2022); Sabur *et al.* (2021)**. The influence of NPK biofertilizer consortia and the role of humic acid as well as hydrogel polymer could have aided in tumbling the nutrient losses, thereby efficient consumption of them by crop resulted in the higher grain count per cob **(Moghadam *et al.,* 2014; Tandon *et al.,* 2021; Deshmukh *et al.,* 2023)**. The minimal competition for resources like light, water and nutrients because of the paired-row spacing declined yield constraining abiotic elements perhaps assisted in the positive output **(Abubakar *et al.,* 2019).** These outcomes are in accordance with **Mahmud *et al.* (2022).**

4.1.2.9. Seed index (weight of 100 grains)

The data on the influence of different hydrogel levels and crop geometric strategies on the seed index (weight of 100 grains) of spring maize is depicted in tables 4.23. In the first year (2022) of the study, the impact of hydrogel levels was found statistically significant. The maximum seed index of 31.7 g was recorded under H_3, followed by H_2 and H_1, while the minimum seed index of 30.6 g was recorded under H_1. H_2 has shared statistical parity with H_3. The crop geometric strategies were also significant in their effect. Among the crop geometric strategies, the highest seed index of 31.5 g was recorded under C_4, while the lowest seed index of 30.8 g was recorded under C_1. C_3 was found to be statistically at par with C_4. The impact of the interaction of both factors was statistically non-significant on the seed index.

In the second year (2023) of study, the impact of hydrogel levels were effective in their effect. Among the hydrogel levels, the maximum seed index of 32.2 g was recorded under H_3, whereas the minimum seed index of 31 g was recorded under H_1. H_2 has shared statistical parity with H_3. The effect of crop geometric strategies was also found statistically significant. Among the crop geometric strategies, the highest seed index of 32.0 g resulted under C_4 and the lowest (31.2 g) was recorded under C_1. C_3 was found to be statistically at par with C_4. The interaction of both factors was found statistically non-significant.

In the mean data, the hydrogel levels were significantly effective in their effect. The highest harvest index of 31.9 g was recorded under H_3, while the lowest (30.8 g) was recorded under H_1. The effect of crop geometric strategies was found statistically significant. H_2 has shared statistical parity with H_3. Among the crop geometric strategies, the highest harvest index of 31.8 g was recorded under C_4, while the lowest (31.0 g) was recorded under C_1. C_3 was found to be statistically at par with C_4. The impact of the interaction of both factors was found statistically non-significant in their effect on the seed index.

The application of hydrogel might have been effective in enhancing the photosynthates accumulation and transport, thus permitted the proper grain filling in the maize (**Shivakumar *et al.,* 2019)**. Analogous outcomes were reported by **Jamwal *et al.* (2023); Tyagi *et al.* (2015)**. The crop geometric strategies have shown a pragmatic increment in the seed index. The results were in line with those of **Kumar & Shankarlingappa, 2017; Sagar *et al.,* 2020; Abdo *et al.,* 2022; Mahmud *et al.* (2022); Reddy *et al.* (2023); Ramesh & Chhabra, 2023; Deshmukh *et al. (*2023);** The collective use of both factors might have contributed in preventing the moisture stress during the pre-anthesis stage and perhaps enabled the satisfactory transport of photosynthates to the reproductive parts, thus enhanced the endosperm cell count, starch granules and finally resulted in superior grain filling **(Singh & Sandhu, 2020).** These findings are similar to those of **Rajavarthini & Kalyanasundaram (2022)**.

4.1.2.10. Shelling percentage with husk (%)

The data on the influence of different hydrogel levels and crop geometric strategies on the shelling percentage with husk (%) of spring maize is depicted in tables 4.22. In the first year (2022) of the study, the influence of hydrogel levels was found statistically non-significant. The maximum shelling percentage of 59.3 was recorded under H_3, followed by H_2 and H_1, while the minimum shelling percentage of 53.0 was recorded under H_1. The crop geometric strategies were also non-significant in their effect. Among the crop geometric strategies, the highest shelling percentage of 59.7 was recorded under C_4, while the lowest shelling percentage of 52.7 was recorded under C_1. The impact of the interaction of both factors was statistically non-significant on the shelling percentage with husk.

In the second year (2023) of the study, the impact of hydrogel levels was found statistically non-significant. The maximum shelling percentage of 63.2 was recorded under H_3, followed by H_2 and H_1, while the minimum shelling percentage of 55.8 was recorded under H_1. The crop geometric strategies were also non-significant in their effect. Among the crop geometric strategies, the highest shelling percentage of 62.1 was recorded under C_4, while the lowest

Table. 4.23. Influence of different hydrogel levels and crop geometric strategies on the yield parameters of spring maize.													
S. no	Factors	Number of rows per cob			Number of grains per row of cob			Number of grains per cob			Seed index (g)		
		2022	**2023**	**Mean**	**2022**	**2023**	**Mean**	**2022**	**2023**	**Mean**	**2022**	**2023**	**Mean**
Hydrogel levels													
1	H_1	10.4	10.9	10.7	28.1	30.5	29.3	293.2	333.0	313.1	30.6	31.0	30.8
2	H_2	11.5	12.2	11.9	29.2	31.7	30.4	335.9	386.9	361.4	31.1	31.5	31.3
3	H_3	12.6	13.2	12.9	30.6	32.9	31.8	383.8	435.2	409.5	31.7	32.2	31.9
CD (at $p \leq 0.05$)		1.4	1.6	1.5	1.9	1.7	1.8	28.2	39.0	33.4	0.719	0.699	0.707
SEm (±)		0.356	0.404	0.379	0.469	0.440	0.454	7.0	9.7	8.3	0.178	0.173	0.175
Crop geometric strategies													
1	C_1	10.7	11.4	11.0	28.6	30.7	29.7	305.1	351.1	328.1	30.8	31.2	31.0
2	C_2	11.3	12.0	11.7	29.1	31.6	30.3	330.1	379.5	354.8	31.0	31.4	31.2
3	C_3	11.8	12.2	12.0	29.4	31.9	30.7	347.3	391.3	369.3	31.3	31.7	31.5
4	C_4	12.2	12.9	12.6	30.1	32.4	31.3	368.0	418.3	393.1	31.5	32.0	31.8
CD (at $p \leq 0.05$)		1.0	0.968	0.987	0.913	0.827	0.853	32.6	33.6	33.0	0.550	0.547	0.547
SEm (±)		0.340	0.323	0.330	0.305	0.276	0.285	10.9	11.3	11.0	0.184	0.183	0.183
A x B		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

shelling percentage of 56.6 was recorded under C_1. The impact of the interaction of both factors was statistically non-significant on the shelling percentage with husk.

In the mean data, the influence of hydrogel levels was found statistically non-significant. The highest shelling percentage of 61.2 was recorded under H_3, followed by H_2 and H_1, while the lowest shelling percentage of 54.4 was recorded under H_1. The crop geometric strategies were also non-significant in their effect. Among the crop geometric strategies, the highest shelling percentage of 60.2 was recorded under C_4, while the lowest shelling percentage of 54.6 was recorded under C_1. The impact of the interaction of both factors was statistically non-significant on the shelling percentage with husk.

4.1.2.11. Shelling percentage without husk (%)

The data on the influence of different hydrogel levels and crop geometric strategies on the shelling percentage without husk (%) of spring maize is depicted in tables 4.24. In the first year (2022) of the study, the impact of hydrogel levels was found statistically non-significant. The highest shelling percentage of 75.4 was recorded under H_3, followed by H_2 and H_1, while the lowest shelling percentage of 72.0 was recorded under H_1. The crop geometric strategies were also non-significant in their effect. Among the crop geometric strategies, the highest shelling percentage of 75.6 was recorded under C_4, while the lowest shelling percentage of 71.2 was recorded under C_1. The impact of the interaction of both factors was statistically non-significant on the shelling percentage with husk.

In the second year (2023) of the study, the influence of hydrogel levels was found statistically non-significant. The highest shelling percentage of 82.7 was recorded under H_3, followed by H_2 and H_1, while the lowest shelling percentage of 76.9 was recorded under H_1. The crop geometric strategies were also non-significant in their effect. Among the crop geometric strategies, the highest shelling percentage of 81.1 was recorded under C_4, while the lowest shelling percentage of 76.8 was recorded under C_1. The impact of the interaction of both factors was statistically non-significant on the shelling percentage with husk.

In the mean data, the impact of hydrogel levels was found statistically non-significant. The highest shelling percentage of 79.1 was recorded under H_3, followed by H_2 and H_1, while the lowest shelling percentage of 74.4 was recorded under H_1. The crop geometric strategies were also non-significant in their effect. Among the crop geometric strategies, the highest shelling percentage of 78.4 was recorded under C_4, while the lowest shelling percentage of 74 .0 was recorded under C_1. The impact of the interaction of both factors was statistically non-significant on the shelling percentage with husk.

Table. 4.24. Influence of different hydrogel levels and crop geometric strategies on the yield parameters of spring maize.

S. no	Factors	Shelling percentage with husk (%)			Shelling percentage without husk (%)			Grain weight per cob (g)		
		2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
Hydrogel levels										
1	H_1	53.0	55.8	54.4	72.0	76.9	74.4	89.8	103.3	96.6
2	H_2	56.4	59.4	57.9	72.9	78.7	75.7	104.6	122.1	113.3
3	H_3	59.3	63.2	61.2	75.4	82.7	79.1	121.7	140.0	130.8
CD (at $p \leq 0.05$)		NS	NS	NS	NS	NS	NS	10.2	13.8	12.0
SEm (±)		1.62	1.24	2.04	1.8	3.2	2.5	2.5	3.4	3.0
Crop geometric strategies										
1	C_1	52.7	56.6	54.6	71.2	76.8	74.0	93.9	109.7	101.8
2	C_2	55.3	59.1	57.2	72.4	79.6	76.0	102.5	119.4	111.0
3	C_3	57.3	60.4	58.7	74.6	80.1	77.3	108.8	124.3	116.5
4	C_4	59.7	62.1	60.2	75.6	81.1	78.4	116.2	133.8	125.0
CD (at $p \leq 0.05$)		NS	NS	NS	NS	NS	NS	10.2	10.7	10.4
SEm (±)		1.82	1.85	1.88	2.7	2.7	2.6	4.8	3.6	3.5
A x B		NS	NS	NS	NS	NS	NS	NS	NS	NS

4.1.2.12. Grain yield (t/ha)

The data regarding the impact of different hydrogel levels and crop geometric strategies on the grain yield (t/ha) of spring maize is depicted in tables 4.24-4.25. In the first year (2022) of study, the hydrogel levels were significant in their effect. There was a substantial enhancement in the grain yield with the increase in the hydrogel dose. Among the hydrogel levels, the highest grain yield of 8.9 t/ha was obtained by H_3, while the lowest grain yield of 7.2 t/ha was obtained by H_1. The effect of crop geometric strategies on grain yield was significantly evident. Among the crop geometric strategies, the maximum grain yield of 8.6 t/ha was obtained by C_4, whereas, the minimum grain yield of 7.6 t/ha was obtained by C_1. The C_2 and C_4 shared statistical parity. There was a substantial effect of the interaction of both factors in the augmentation of grain yield. The highest grain yield of 9.3 t/ha was obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 ×25 cm) with the seed capsule), while the lowest grain yield of 6.7 t/ha was obtained by H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule) has shared statistical parity with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 ×25 cm) with the seed capsule).

In the second year (2023) of the study, the impact of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum grain yield of 9.9 t/ha was obtained by H_3, while the minimum grain yield of 7.7 t/ha was obtained by H_1. The effect of crop geometric strategies was found statistically significant. Among the crop geometric strategies, the maximum grain yield of 9.2 t/ha resulted under C_4, followed by C_3, C_2 and C_1, whereas, the minimum grain yield of 8.4 t/ha resulted under C_1. The interaction effect of both factors was found statistically significant. Overall, the highest grain yield of 10.5 t/ha resulted under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule), whereas, the lowest grain yield of 7.4 t/ha resulted under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).

Regarding the mean data, the hydrogel levels were significant in their effect. Among the hydrogel levels, the maximum grain yield of 9.5 t/ha resulted under H_3 followed by H_2 (8.4 t/ha) and H_1 (7.5 t/ha). The effect of crop geometric strategies was also found statistically significant. Among all the crop geometric strategies, the maximum grain yield of 8.9 t/ha resulted under C_4, while the minimum grain yield of 8.0 t/ha resulted under C_1. A significant impact of both factors was found in enhancing the grain yield. The maximum grain yield of 9.9 t/ha was obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the

Table. 4.25. Impact of different hydrogel levels and crop geometric strategies on the yield parameters of spring maize.

S. no	Factors	Grain yield (t/ha)			Stover yield (t/ha)			Biological yield (t/ha)			Harvest index (%)		
		2022	**2023**	**Mean**	**2022**	**2023**	**Mean**	**2022**	**2023**	**Mean**	**2022**	**2023**	**Mean**
Hydrogel levels													
1	H_1	7.2	7.7	7.5	13.1	14.2	13.6	21.9	22.4	22.1	32.9	34.4	33.6
2	H_2	8.1	8.8	8.5	14.3	15.3	14.8	23.5	24.6	24.1	34.5	35.6	35.0
3	H_3	8.9	9.9	9.5	15.7	16.8	16.3	25.1	27.2	26.2	35.7	36.5	36.1
CD (at $p \leq 0.05$)		0.053	0.095	0.045	0.370	0.092	0.142	0.305	0.176	0.164	0.491	0.204	0.22
SEm (±)		0.013	0.024	0.011	0.092	0.023	0.035	0.076	0.044	0.041	0.101	0.051	0.055
Crop geometric strategies													
1	C_1	7.6	8.4	8.0	13.6	14.9	14.2	22.5	23.7	23.1	33.5	35.2	34.4
2	C_2	8.1	8.6	8.4	14.4	15.3	14.8	23.5	24.4	24.0	34.4	35.4	34.9
3	C_3	8.1	9.0	8.6	14.5	15.6	15.0	23.6	25.1	24.3	34.4	35.7	35.0
4	C_4	8.6	9.2	8.9	15.0	16.0	15.5	24.4	25.7	25.1	35.1	35.8	35.5
CD (at $p \leq 0.05$)		0.126	0.100	0.055	0.244	0.132	0.134	0.465	0.168	0.253	0.877	0.323	0.385
SEm (±)		0.042	0.034	0.018	0.075	0.044	0.045	0.155	0.056	0.084	0.236	0.108	0.129
A x B		0.196	0.177	0.093	0.494	0.217	0.244	NS	0.305	NS	NS	0.523	NS

Table. 4.26. Interaction effect of different hydrogel levels and crop geometric strategies on the grain yield (t/ha) of the spring maize.

Grain yield (2022)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	6.7	7.5	8.4	7.6
	C_2	7.3	8.1	8.9	8.1
	C_3	6.9	8.3	9.2	8.1
	C_4	7.8	8.6	9.4	8.6
Mean		7.2	8.1	9.0	
		CD (at p≤ 0.05)	0.196		
		SEm (±)	0.064		

Grain yield (2023)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	7.4	8.4	9.3	8.4
	C_2	7.5	8.6	9.8	8.6
	C_3	7.9	8.9	10.2	9.0
	C_4	8.1	9.2	10.5	9.2
Mean		7.7	8.8	9.9	
		CD (at p≤ 0.05)	0.177		
		SEm (±)	0.056		

Grain yield (Mean)		Hydrogel levels			
		H_1	H_2	H_3	Mean
Crop geometric strategies	C_1	7.1	8.0	8.9	8.0
	C_2	7.4	8.4	9.3	8.4
	C_3	7.4	8.6	9.7	8.6
	C_4	7.9	8.9	9.9	8.9
Mean		7.5	8.4	9.4	
		CD (at p≤ 0.05)	0.093		
		SEm (±)	0.030		

seed capsule), while the minimum grain yield of 7.1 t/ha was obtained by H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).

In 2022, the high-temperature extremes and lack of rainfall severely impacted the grain yield under control. The constant temperatures of 36°C between the mid-vegetative to the reproductive stage has affected the reproductive stages like tasselling, silking, grain filling and maturity. The hydrogel application aided in stress mitigation by improving the rhizosphere moisture conditions that augmented nutrient holding, uptake and translocation from source to sink and further broadening the grain filling rate. **(Kumar *et al.,* 2020; Roy *et al.,* 2019; Jamwal *et al.,* 2023; Rajavarthini & Kalyanasundaram, 2022).** The NPK biofertilizer consortium was possibly efficient in the nutrient fixation and mobilization that led to the increment of grain attributes that resonated in superior grain yield **(Tandon *et al.,* 2021; Sivamurugan *et al.,* 2018; Reddy *et al.,* 2023; Prayogo *et al.,* 2021; Kumar *et al.,* 2022; Thamatam and Mehera, 2022;).** The humic acid application could have aided in enhancing the grain yield to an extent **(Abdo *et al.,* 2022; Khan *et al.,* 2019)**. The increased growth and yield contributing attributes might have resulted in the remarkable grain yield enhancement **(Shivakumar *et al.,* 2019; Abubakar *et al.,* 2019).** Competition among the plants is an additional problem for the crop besides the stress. The paired-row spacing could have aided in the better exploitation of the resources and led to increased grain yield **(Liu *et al.,* 2020).**

4.1.2.11. Stover yield (t/ha)

The data pertaining to the impact of different hydrogel levels and crop geometric strategies on the stover yield (t/ha) of spring maize is depicted in tables 4.24 and 4.26. In the first year (2022) of study, the influence of hydrogel levels on the stover yield was significantly evident. The highest stover yield of 15.7 t/ha resulted under H_3, while the lowest stover yield of 13.1 t/ha resulted under H_1. The impact of crop geometric strategies was also found statistically significant. Among the crop geometric strategies, the maximum stover yield of 15.0 t/ha was recorded under C_4, while the minimum stover yield of 13.6 t/ha was recorded under C_1. The C_2 and C_3 have shared statistical parity with each other. The interaction effect of both factors was found statistically significant on the stover yield. The highest stover yield of 16.1 t/ha was obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule), while the lowest stover yield of 12.2 t/was obtained by H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule) shared statistical parity with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule).

In the second year (2023) of study, hydrogel levels significantly influenced the stover yield. Among the hydrogel levels, the maximum stover yield of 16.8 t/ha resulted under H_3, while the minimum stover yield of 14.2 t/ha resulted under H_1. The effect of crop geometric strategies was statistically significant. Among the crop geometric strategies, the maximum stover yield of 16.0 t/ha was recorded under C_4, whereas the minimum stover yield of 14.9 t/ha was recorded under C_1. The interaction effect of both factors was found statistically significant. The maximum stover yield of 17.2 t/ha was obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule), while the minimum stover yield of 13.8 t/ha was obtained by H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 ×25 cm)). The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule) has shared statistical parity with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule).

In the mean data, the hydrogel levels were significant in their effect. Among the hydrogel levels, the highest stover yield of 16.3 t/ha resulted under H_3, while the minimum stover yield of 13.6 t/ha resulted under H_1. The effect of hydrogel levels was found statistically significant. Among the crop geometric strategies, the highest stover yield of 15.5 t/ha was obtained by C_4, while the lowest stover yield was obtained by C_1. The impact of the interaction of both factors was statistically significant on stover yield. The highest stover yield of 16.6 t/ha resulted under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule), while the lowest stover yield of 13.0 t/ha resulted under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 ×25 cm)). The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 ×25 cm) with seed capsule) has shared statistical parity with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule).

The stover yield increment was proportional to the dose of hydrogel. The abiotic stress impacted the stover yield mainly in case of control. The progressive effect of hydrogel intensified the dry matter accumulation (**Chikarango *et al.*, 2021**). The polymer can impound the moisture stress by mitigation and increase the cell growth eventually enhanced the plant size and dry weight **(Chaithra & Sridhara, 2018)**. The astounding response of growth attributes might have resonated in the stover yield increment **(Roy *et al.,* 2019).** Similar outcomes are reported by **Rajavarhtini & Kalyanasundaram (2022); Jamwal *et al.* (2023).** The NPK biofertilizer consortia might have increased the accessibility of macronutrients to plants and enhanced the stover yield **(Reddy *et al.,* 2023).** Sufficient N availability might have promoted higher photosynthetic activity, led to greater plant height, leaf count and leaf area; while P availability enhanced root proliferation which led to better anchorage, water uptake as well as nutrient distribution, supported overall plant structure as well as biomass accumulation;

Table. 4. 27. Interaction effect of different hydrogel levels and crop geometric strategies on the stover yield (t/ha) of the spring maize.

Stover yield (2022)		Hydrogel levels			
		H1	**H2**	**H3**	**Mean**
Crop geometric strategies	**C1**	12.1	13.5	15.2	13.6
	C2	13.4	14.2	15.6	14.4
	C3	12.7	14.7	16.0	14.5
	C4	14.0	14.9	16.1	15.0
Mean		13.1	14.3	15.7	
		CD (at p≤ 0.05)	0.494		
		SEm (±)	0.145		

Stover yield (2023)		Hydrogel levels			
		H1	**H2**	**H3**	**Mean**
Crop geometric strategies	**C1**	13.7	14.5	16.3	14.9
	C2	13.9	15.2	16.6	15.3
	C3	14.2	15.7	17.0	15.6
	C4	14.8	16.0	17.2	16.0
Mean		**14.2**	15.3	16.8	15.4
		CD (at p≤ 0.05)	0.217		
		SEm (±)	0.070		

Stover yield (Mean)		Hydrogel levels			
		H1	**H2**	**H3**	**Mean**
Crop geometric strategies	**C1**	13.0	14.0	15.8	14.2
	C2	13.7	14.7	16.1	14.8
	C3	13.5	15.2	16.5	15.1
	C4	14.4	15.4	16.6	15.5
Mean		13.6	14.8	16.3	14.9
		CD (at p≤ 0.05)	0.244		
		SEm (±)	0.076		

while K availability improved stem thickness, resistance to lodging and drought tolerance that ensured better structural integrity and prolonged vegetative growth (**Prayogo *et al.,* 2021; Kumar *et al.,* 2022**). The paired-row spacing led to enhanced photosynthetic activity and increased the photoassimilates in the straw ultimately resulted in higher straw yield **(Thamatam & Mehera, 2022; Gohil *et al.,* 2021; Tandon *et al.,* 2021)**. The commendatory hydro-thermal regimes with the combination of both factors and the prevalence of good weather conditions might have reduced the losses due to the evaporation, transpiration and runoff. Thus, amended the mitigation, nutrient mineralization and accessibility during the critical stages of the crop cycle **(Singh & Sandhu, 2020).**

4.1.2.12. Biological yield (t/ha)

The data regarding the impact of different hydrogel levels and crop geometric strategies on the biological yield (t/ha) of spring maize is depicted in tables 4.24 and 4.27. In the first year (2022) of study, the impact of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest biological yield of 25.1 t/ha resulted under H_3 and the lowest (21.9 t/ha) resulted under H_1. The effect of crop geometric strategies was also found statistically significant. Among the crop geometric strategies, the maximum biological yield of 24.4 t/ha resulted under C_4, while C_1 resulted in the minimum biological yield of 22.5 t/ha. The C_2 and C_3 have shared statistical parity with each other. The results of biological yield revealed that the interaction effect of both factors was non-significant. The highest biological yield of 25.9 t/ha was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). While H_1C_1 (hydrogel 0 kg/ha + normal spacing 70 × 25 cm)) resulted in a minimum biological yield of 20.6 t/ha.

In the second year (2023) of study, effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest biological yield of 27.2 t/ha was recorded under H_3, while the lowest biological yield of 22.4 t/ha was recorded under H_1. The effect of crop geometric strategies was also found statistically significant. Among the crop geometric strategies, the maximum biological yield of 25.7 t/ha was recorded under C_4, while the minimum of 23.7 t/ha was recorded under C_1. The interaction effect of both factors on biological yield was found statistically significant. The maximum biological yield of 28.1 t/ha was obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) whereas, the minimum biological yield of 21.6 t/ha was obtained by H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).

In the mean data, the effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest biological yield of 26.2 t/ha was obtained by H_3 while the lowest biological yield was obtained by H_1. The effect of crop geometric strategies was significantly evident. Among the crop geometric strategies, the maximum biological yield of 25.1 t/ha was recorded under C_4, while the minimum biological yield of 23.1 t/ha was recorded under C_1. The interaction effect of both factors on biological yield was found statistically non-significant. The maximum biological yield of 27.0 t/ha was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule), while the minimum biological yield of 21.1 t/ha was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 ×25 cm)).

The biological yield is the crucial parameter that reflects the above-ground biomass i.e., total dry matter accumulation by the plant **(Ramesh & Chhabra, 2023)**. The employment of hydrogel enhanced the biological yield over the control **(Roy *et al.,* 2019).** The utilization of fertilizers, biofertilizer consortium and humic acid along with the paired-row spacing enabled the mineralization and better exploitation of the resources and ultimately biological yield **(Abdo *et al.,* 2022; Khan *et al.,* 2019).** The progressive effect of both factors on the grain and stover yield could have improved biological yield **(Shivakumar *et al.,* 2019; Jamwal *et al.,* 2023).**

4.1.2.13. Harvest index (%)

The data on the influence of various hydrogel levels and crop geometric strategies on the harvest index (%) of spring maize is depicted in tables 4.24 and 4.27. In the first year (2022) of the study, the effect of hydrogel levels was found statistically significant. The maximum harvest index of 35.7% resulted under H_3, while the minimum harvest index of 32.9 % resulted under H_1. The effect of crop geometric strategies was found significant. Among the crop geometric strategies, the maximum harvest index of 35.1 % was obtained by C_4. The C_2 and C_3 have shared statical parity with C_4. The interaction of both factors showed a non-significant impact on the harvest index. Overall, the maximum harvest index of 36.1% and the lowest harvest index of 32.6% were recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) and H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) respectively.

In the second year (2023) of study, the hydrogel levels were found statistically significant in their effect. Among the hydrogel levels, the maximum harvest index of 36.5 % resulted under H_3, whereas the minimum harvest index of 34.4% resulted under H_1. The effect of crop geometric strategies was found statistically significant. Among the crop geometric strategies, the maximum harvest index of 35.8% was obtained by C_4. The minimum harvest index of 35.2% was obtained by C_1. Geometric strategy C_3 has shared statistical parity with C_4, while C_2 and C_3 have shared partial statistical parity with each other. The interaction effect of both factors was found statistically significant. The maximum harvest index of 37.2 % was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule), while the minimum harvest index of 34.2 % was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). The treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 ×25 cm) with seed capsule) has shared statistical parity with H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule).

Table. 4. 28. Interaction effect of different hydrogel levels and crop geometric strategies on the biological yield (t/ha) and harvest index of the spring maize.

Biological yield (2023)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	21.6	23.4	26.2	22.5
	C_2	22.0	24.3	26.9	23.5
	C_3	22.6	25.1	27.7	23.6
	C_4	23.4	25.6	28.1	24.4
Mean		21.9	**22.4**	24.6	27.2
		CD (at p≤ 0.05)	0.305		
		SEm (±)	0.095		
Harvest index (%) (2023)		**Hydrogel levels**			
		H_1	**H_2**	**H_3**	**Mean**
Crop geometric strategies	**C_1**	34.1	35.8	35.7	35.2
	C_2	34.3	35.5	36.3	35.4
	C_3	34.8	35.5	36.7	35.6
	C_4	34.4	35.8	37.2	35.8
Mean		**22.4**			34.4
		CD (at p≤ 0.05)	0.523		
		SEm (±)	0.170		

In the mean data, the hydrogel levels were found statistically significant in their effect. The maximum harvest index of 36.1% resulted under H_3 and the minimum harvest index of 33.6 % resulted under H_1. The effect of crop geometric strategies was also found statistically significant. Among the crop geometric strategies, the maximum harvest index of 35.5 %

resulted under C_4, while the minimum harvest index of 34.4 % resulted under C_1. The C_2 and C_3 have shared statistical parity with each other. The impact of the interaction of both factors was found statistically non-significant on the harvest index. Overall, a maximum harvest index of 36.6% was found under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule), while the minimum harvest index of 33.4% was found under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 ×25 cm)).

The harvest index is pivotal in defining the reproductive efficiency of the plants i.e., conversion of resources stored in the vegetative parts to the reproductive part i.e., grain. The improved harvest index might be because of the improved plant-water relations, the excellent translocation of the photo-assimilates to the grains which led to the firm discrete grain yield (**Shivakumar *et al.,* 2019**). The microbial consortia of macronutrients might have also improved the uptake and translocation from source to sink (**Reddy *et al.,* 2023).** The integration of both factors might have done their aforementioned functions effectively and led to a higher harvest index (**Ahmed *et al.,* 2022; Jamwal *et al.,* 2023).**

4.2. Effect of the irrigation and crop geometric strategies in improving the quality and soil parameters of spring maize

4.2.1. Soil studies

The influence of different hydrogel levels as well as the crop geometric strategies in improving soil parameters like available N, P and K content at harvest, the number of irrigations given and irrigation intervals in individual main plots are discussed below. The data on the influence of different hydrogel levels and crop geometric strategies on N, P and K status at harvest, the number of irrigations given and irrigation intervals in individual main plots is depicted in tables 4.27-4.28.

4.2.1.1. Available Nitrogen (N) at harvest

In the first year (2022) of study, the influence of hydrogel levels was found statistically non-significant. Among the hydrogel levels, the maximum available N of 191.9 kg/ha resulted under H_1, while the minimum available N of 181.3 kg/ha resulted under H_3. The effect of crop geometric strategies was found statistically non-significant. Among crop geometric strategies, the maximum available N of 189.9 kg/ha resulted under C_1, while the minimum available N of 183.2 kg/ha resulted under C_4. The impact of the interaction of both factors was statistically non-significant in improving available N in the soil.

In the second year (2023) of study, the influence of hydrogel levels was found statistically non-significant. Among the hydrogel levels, the maximum available N of 185.4 kg/ha resulted under H_1, while the minimum available N of 171.7 kg/ha resulted under H_3. The effect of crop geometric strategies was found statistically non-significant. Among crop geometric strategies, the maximum available N of 182.2 kg/ha resulted under C_1, while the minimum available N of 174.6 kg/ha resulted under C_4. The impact of the interaction of both factors was statistically non-significant in improving available N in the soil.

In the mean data, the impact of hydrogel levels on the available soil N was found statistically significant. Among the hydrogel levels, the maximum available N of 188.7 kg/ha resulted under H_1, while the minimum available N of 176.5 kg/ha resulted under H_1.H_2 has shared statistical parity with H_1. The crop geometric strategies were non-significant in the improvement of soil available N. Among the crop geometric strategies, the maximum available N of 186.0 kg/ha resulted under C_1, while the minimum available N of 178.9 kg/ha resulted under C_4. The interaction of both factors was found statistically non-significant in improving the available N in the soil.

4.2.1.1.2. Available phosphorous (P) in the soil

In the first year (2022) of study, the influence of hydrogel levels was found statistically non-significant. Among the hydrogel levels, the maximum available P of 21.1 kg/ha resulted under H_1, while the minimum available P of 18.9 kg/ha resulted under H_3. The effect of crop geometric strategies was found statistically non-significant. Among crop geometric strategies, the maximum available P of 20.4 kg/ha resulted under C_1, while the minimum available P of 19.3 kg/ha resulted under C_4. The impact of the interaction of both factors was statistically non-significant in improving available P in the soil.

In the second year (2023) of study, the influence of hydrogel levels was found statistically non-significant. Among the hydrogel levels, the maximum available P of 20.1 kg/ha resulted under H_1, while the minimum available P of 18.2 kg/ha resulted under H_3. The effect of crop geometric strategies was found statistically non-significant. Among crop geometric strategies, the maximum available P of 20.4 kg/ha resulted under C_1, while the minimum available P of 19.3 kg/ha resulted under C_4. The impact of the interaction of both factors was statistically non-significant in improving available P in the soil.

In the mean data, the impact of hydrogel levels on the available soil P was found statistically significant. Among the hydrogel levels, the maximum available P of 20.3 kg/ha resulted under H_1, while the minimum available P of 18.2 kg/ha resulted under H_1. The crop geometric strategies were non-significant in the improvement of soil available P. Among the crop geometric strategies, the maximum available P of 19.7 kg/ha resulted under C_1, while the minimum available P of 18.5 kg/ha resulted under C_4. The interaction of both factors was found statistically non-significant in improving the available P in the soil.

Table.4.29. Influence of different hydrogel levels and crop geometric strategies on the available soil N, P and K (kg/ha) at harvest.

S. no	Factors	Available N in the soil (kg/ha)			Available P in the soil (kg/ha)			Available K in the soil (kg/ha)		
		2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
	Hydrogel levels									
1	Without hydrogel application in soil	191.9	185.4	188.7	21.1	20.1	20.3	145.7	136	140.9
2	With hydrogel application in the soil at1.5 kg/ha	186.4	178.3	182.3	19.7	19.2	19.1	138.2	132.7	135.4
3	With hydrogel application in the soil at 3 kg/ha	181.3	171.7	176.5	18.9	18.2	18.2	133.4	127.1	130.3
	CD (at p≤ 0.05)	NS	NS	7.6	NS	NS	0.904	NS	NS	NS
	SEm (±)	2.7	3.0	1.9	0.586	0.462	0.224	2.5	3.7	2.6
	Crop geometric strategies									
1	Normal spacing (70 × 25 cm)	189.9	182.2	186.0	20.4	17.8	19.7	141.8	133.7	137.7
2	Paired-row spacing (55 - 85 × 25 cm)	187.2	178.8	183.0	20.1	17.3	19.4	140.1	132.6	136.4
3	Normal spacing (70 × 25 cm) with the seed capsule	185.9	178.3	182.1	19.8	17.1	19.1	137.3	131.5	134.4
4	Paired-row spacing (55 - 85 × 25 cm) with the seed capsule	183.2	174.6	178.9	19.3	16.4	18.5	137.2	129.9	133.6
	CD (at p≤ 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
	SEm (±)	2.8	3.7	2.6	0.758	0.937	0.655	4.0	3.3	3.0
	A x B	NS	NS	NS	NS	NS	NS	NS	NS	NS
Initial available soil N,P and K (kg/ha)		206.85	209.13	207.98	23.72	23.88	23.80	165.6	167.1	166.37

4.2.1.1.3. Available potassium (K) in the soil:

In the first year (2022) of study, the influence of hydrogel levels was found statistically non-significant. Among the hydrogel levels, the maximum available K of 145.7 kg/ha resulted under H_1, while the minimum available K of 133.4 kg/ha resulted under H_3. The effect of crop geometric strategies was found statistically non-significant. Among crop geometric strategies, the maximum available K of 141.8 kg/ha resulted under C_1, while the minimum available K of 137.2 kg/ha resulted under C_4. The impact of the interaction of both factors was statistically non-significant in improving available P in the soil.

In the second year (2023) of study, the influence of hydrogel levels was found statistically non-significant. Among the hydrogel levels, the maximum available K of 136.0 kg/ha resulted under H_1, while the minimum available K of 127.1 kg/ha resulted under H_3. The effect of crop geometric strategies was found statistically non-significant. Among crop geometric strategies, the maximum available K of 133.7 kg/ha resulted under C_1, while the minimum available K of 129.9 kg/ha resulted under C_4. The impact of the interaction of both factors was statistically non-significant in improving available K in the soil.

In the mean data, the impact of hydrogel levels on the available soil K was found statistically non-significant. Among the hydrogel levels, the maximum available K of 140.9 kg/ha resulted under H_1, while the minimum available K of 130.3 kg/ha resulted under H_1. The crop geometric strategies were non-significant in the improvement of soil available K. Among the crop geometric strategies, the maximum available K of 137.7 kg/ha resulted under C_1, while the minimum available K of 133.6 kg/ha resulted under C_4. The interaction of both factors was found statistically non-significant in improving the available K in the soil.

The treatments with higher nutrient uptake recorded poor available soil N, P and K status. Similarly, lower nutrient uptake treatments recorded higher available soil N, P and K status. This could be due to best-performing treatments utilising the available nutrients in the soil drastically, eventually depleted the soil N, P and K. While the poorly performed plants were unable to utilize the available nutrients to their full potential and led to higher available soil N, P and K after harvest. Similar findings of higher biomass production with higher nutrient uptake resulting in depleting nutrients in the soil were reported by **Shivakumar et al. (2019 and Jeevan et al. (2023).**

4.2.1.2. Irrigation strategies

4.2.1.2.1. Number of irrigations given in individual main plots

Irrigation was applied to the individual main plots after assessing their moisture content. In 2022, the maximum number of irrigations (13) was applied under H_1, followed by H_2 (11)

Table. 4.30. Chronological record of irrigation schedule and irrigation intervals during the experiment.

S. no	Irrigation number	Main plot (H_1)						Main plot (H_2)						Main plot (H_3)					
		2022	DAS	Irrigation interval	2023	DAS	Irrigation interval	2022	DAS	Irrigation interval	2023	DAS	Irrigation interval	2022	DAS	Irrigation interval	2023	DAS	Irrigation interval
1	1st	27/02/22	03	0	27/02/23	03	0	27/02/22	03	0	27/02/23	3	0	27/02/22	03	0	27/02/23	03	0
2	2nd	10/03/22	14	11	07/03/23	11	8	12/03/22	16	13	11/03/23	15	12	15/03/22	19	16	13/03/23	17	14
3	3rd	16/03/22	20	6	15/03/23	19	8	20/03/22	24	8	11/04/23	46	31	26/03/22	30	11	11/04/23	46	29
4	4th	24/03/22	28	8	11/04/23	46	27	28/03/22	32	8	27/04/23	62	16	07/04/22	42	12	13/05/23	78	32
5	5th	02/04/22	37	9	25/04/23	60	14	06/04/22	41	9	10/05/23	75	13	20/04/22	55	13			
6	6th	10/04/22	45	8	06/05/23	71	11	18/04/22	53	12				30/04/22	65	10			
7	7th	18/04/22	53	8	20/05/23	85	14	27/04/22	62	9				14/05/22	79	14			
8	8th	26/04/22	61	8				05/05/22	70	8				04/06/22	100	21			
9	9th	03/05/22	68	7				14/05/22	79	9									
10	10th	10/05/22	75	7				01/06/22	97	18									
11	11th	19/05/22	84	9				11/06/22	107	10									
12	12th	01/06/22	97	13															
13	13th	09/06/22	105	8															
Average irrigation interval				7.8			11.7			9.5			14.4			12.1			18.8

and a minimum number of irrigations (8) under H_3. In 2023, the maximum number of irrigations (7) was applied under H_1, followed by H_2 (5) and the minimum number of irrigations (4) under H_3.

4.2.1.2.2. Irrigation intervals

The irrigation interval is the duration between two irrigations in the main plots. The irrigation interval between two irrigations and the average irrigation interval during the cropping season is mentioned in the table 4.29. In the year 2022, the shortest average irrigation interval of 7.8 days was recorded under H_1. While the longest average irrigation interval of 12.1 days was recorded under H_3. A median average irrigation interval of 9.8 days was recorded under H_2. In the year 2023, the shortest average irrigation interval of 11.7 days was recorded under H_1, whereas the longest average irrigation interval of 14.4 days was recorded under H_3. A median average irrigation interval of 18.8 days was recorded under H_2. The number of irrigations given were reduced with the enhancement in the dose of the hydrogel. While the irrigation intervals were increased with the hydrogel dose.

The contrasting weather conditions have resulted in varied irrigation requirements for the crop in both years. In the year 2022, the heavy heat wave effect and less number of rainy days (5) increased the need for irrigation. Thus, increasing the irrigation number and shrinking the irrigation interval. In the year 2023, the favourable weather conditions and consistent rainfall throughout the cropping season (with 30 rainy days) resulted in less demand for irrigation and longer irrigation intervals. The hydrogel amendment has increased the WHC of the soil, thereby holding the moisture for a prolonged duration and reducing the need for irrigation. Eventually, increased the irrigation intervals. Similar positive results with hydrogel amendment on the moisture studies were reported by **Jeevan *et al.* (2023); Cholavardhan *et al.* (2023); Abd El-Naby *et al.* (2024); Patel *et al.* (2023); Manish *et al.* (2023).**

4.2.2. Quality parameters

4.2.2.1. Nutrient uptake (kg/ha)

The total uptake of macronutrients like N, P and K by spring maize plant i.e., in grain, stover and total (grain + stover) is discussed below. The data on the influence of different levels of hydrogel and crop geometric strategies on uptake of N, P and K (kg/ha) is depicted in tables 4.30-4.32.

4.2.2.1.1. Total uptake of nitrogen (N) (kg/ha)

a. Nitrogen uptake (kg/ha) in grains

In the first year (2022) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum N uptake of 60.0 kg/ha resulted under

H_3, while H_1 resulted in the minimum N uptake of 53.5 kg/ha. H_2 has shared statistical parity with H_3. The crop geometric strategies were effective in their impact on the improvement of N uptake in the grains. Among the crop geometric strategies, the maximum N uptake of 58.6 kg/ha resulted under C_4, while C_1 resulted in the minimum N uptake of 54.4 kg/ha. C_2 and C_3 have shared statistical parity with C_4. The impact of the interaction of both factors was found to be non-significant on the N uptake in the grains.

In the second year (2023) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum N uptake of 65.5 kg/ha resulted under H_3, while H_1 resulted in the minimum N uptake of 58.7 kg/ha. H_2 has shared statistical parity with H_3. The crop geometric strategies were effective in their impact on the improvement of N uptake in the grains. Among the crop geometric strategies, the maximum N uptake of 64.1 kg/ha resulted under C_4, while C_1 resulted in the minimum N uptake of 60.1 kg/ha. C_2 and C_3 have shared statistical parity with C_4. The impact of the interaction of both factors was found to be non-significant on the N uptake in the grains.

In the mean data, hydrogel levels were significantly effective in the improvement of N uptake in grains. Among the hydrogel levels, the maximum grain N of 62.7 kg/ha was obtained by H_3, while the minimum grain N of 56.1 kg/ha was obtained by H_1. H_2 has shared statistical parity with H_3. Among the crop geometric strategies, the maximum grain N of 61.4 kg/ha resulted under C_4, while the minimum grain N of 57.2 kg/ha resulted under C_1. C_2 and C_3 have shared statistical parity with C_4. The interaction effect of both factors influenced the grain N uptake non-significantly.

b. Nitrogen uptake (kg/ha) in stover

In the first year (2022) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum N uptake of 44.5 kg/ha resulted under H_3, whereas H_1 resulted in the minimum N uptake of 36.9 kg/ha. H_2 has shared statistical parity with H_3. The crop geometric strategies significantly impacted the improvement of N uptake in the stover. Among the crop geometric strategies, the minimum N uptake of 42.6 kg/ha resulted under C_4, while C_1 resulted in the minimum N uptake of 38.5 kg/ha. C_3 has shared statistical parity with C_4. The interaction of both factors was found statistically non-significant.

In the second year (2023) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum N uptake of 52.0 kg/ha resulted under H_3, whereas H_1 resulted in the minimum N uptake of 44.5 kg/ha. H_2 has shared statistical parity with H_3. The crop geometric strategies significantly impacted the improvement of N uptake in the stover. Among the crop geometric strategies, the maximum N uptake of 50.2

kg/ha resulted under C_4, while C_1 resulted in the minimum N uptake of 45.9 kg/ha. C_3 has shared statistical parity with C_4. The interaction of both factors was found statistically non-significant.

In mean data, the impact of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum N uptake of 48.4 kg/ha resulted under H_3, whereas H_1 resulted in the minimum N uptake of 40.7 kg/ha. H_2 has shared statistical parity with H_3. The crop geometric strategies significantly impacted the improvement of N uptake in the stover. Among the crop geometric strategies, the maximum N uptake of 46.4 kg/ha resulted under C_4, while C_1 resulted in the minimum N uptake of 42.2 kg/ha. C_3 has shared statistical parity with C_4. The interaction of both factors was found statistically non-significant.

c. Total nitrogen uptake (kg/ha)

In the first year (2022) of study, the influence of hydrogel levels on the total uptake of N was found statistically significant. Among the hydrogel levels, the maximum total N uptake of 104.4 kg/ha was recorded under H_3, while H_1 resulted in a minimum total N uptake of 90.4 kg/ha. The effect of crop geometric strategies was found statistically significant. Among the crop geometric strategies, the highest total N uptake of 101.1 kg/ha was recorded under C_4, while C_1 resulted in a lowest total N of 92.9 kg/ha. The interaction effect of both factors was found statistically non-significant.

In the second year (2023) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest total uptake of N of 117.5 kg/ha was obtained by H_3, while the lowest total uptake of N of 103.1 kg/ha was obtained by H_1. The crop geometric strategies were significantly effective in the improvement of total N uptake. Among the crop geometric strategies, the maximum total uptake of N of 114.3 kg/ha resulted under C_4, while the minimum total uptake of N of 106.0 kg/ha resulted under C_1. C_3 has shared statistical parity with C_4. The interaction of hydrogel levels and crop geometric strategies had a non-significant impact on the total uptake of N.

In the mean data, the effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum total uptake of N of 111.0 kg/ha resulted under H_3, while the minimum total uptake of N of 96.8 kg/ha resulted under H_1. The impact of crop geometric strategies on the total N uptake was found significant. Among the crop geometric strategies, the maximum total uptake of N of 107.7 kg/ha resulted under C_4, while the minimum total uptake of N of 99.5 kg/ha resulted under C_1. The impact of the interaction of both factors was found to be non-significant on total N uptake in plants.

4.2.2.1.2. Total uptake of phosphorus (P) (kg/ha)

a. Phosphorus uptake (kg/ha) in grains

In the first year (2022) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum uptake of P of 14.3 kg/ha resulted under H_3, while H_1 resulted in the minimum uptake of P of 11.4 kg/ha. H_2 was found to be statistically at par with H_3. The impact of crop geometric strategies on P uptake was also found statistically significant. Among the crop geometric strategies, the highest uptake of P of 13.6 kg/ha resulted under C_4, while the lowest uptake of P of 11.9 kg/ha resulted under C_1. C_2 and C_3 have shared statistical parity with C_4. The interaction of both factors non-significantly influenced the uptake of P in grains.

In the second year (2023) of study, the influence of hydrogel levels was effective in their effect. Among the hydrogel levels, the highest uptake of P of 15.0 kg/ha resulted under H_3, while the lowest uptake of P of 12.1 kg/ha resulted under H_1. H_2 was found to be statistically at par with H_3. The effect of crop geometric strategies on the P uptake in grain was found statistically significant. Among the crop geometric strategies, the highest uptake of P of 14.3 kg/ha resulted under C_4, while the lowest uptake of P of 12.7 kg/ha resulted under C_1. C_2 and C_3 have shared statistical parity with C_4. The interaction of both factors had a non-significant impact on grain uptake of P.

In the mean data, the influence of hydrogel levels on grain P uptake was found statistically significant. Among the hydrogel levels, the maximum uptake of grain P of 14.7 kg/ha resulted under H_3, while the minimum grain uptake of P of 11.8 kg/ha resulted under H_1. The impact of crop geometric strategies was found statistically significant. Among the crop geometric strategies, the maximum grain P uptake of 14.0 kg/ha was recorded under C_4, while the minimum grain uptake of P of 12.3 kg/ha was recorded under C_1. C_2 and C_3 have shared statistical parity with C_4. The interaction effect of hydrogel levels and crop geometric strategies has shown a significant influence on the uptake of P in the grains.

b. Phosphorus uptake (kg/ha) in stover

In the first year (2022) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest uptake of P of 12.7 kg/ha resulted under H_3, while the lowest uptake of P of 9.5 kg/ha resulted under H_1. H_2 was found to be statistically at par with H_3. The crop geometric strategies were significantly effective in their effect. Among the crop geometric strategies, the maximum uptake of P of 12.0 kg/ha resulted under C_4, while C_1 resulted in the minimum P uptake of 10.2 kg/ha. C_3 has shared statistical parity with C_4. The impact of the interaction of both factors influenced the uptake of P by stover was found to be non-significant.

In the second year (2023) of study, the hydrogel levels were effective in their effect. Among the hydrogel levels, the highest uptake of P of 13.3 kg/ha resulted under H_3, while the lowest uptake of P of 10.1 kg/ha resulted under H_1. H_2 was found to be statistically at par with H_3. The crop geometric strategies were significantly effective in their effect. Among the crop geometric strategies, the highest uptake of P of 12.6 kg/ha resulted under C_4, while the lowest uptake of P of 10.8 kg/ha resulted under C_1. C_3 has shared statistical parity with C_4. The interaction of both factors has shown a non-significant enhancement of uptake of P in stover.

In the mean data, effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest uptake of P of 13.0 kg/ha resulted under H_3, while the lowest uptake of P of 9.8 kg/ha resulted under H_1. H_2 was found to be statistically at par with H_3. The crop geometric strategies were significantly effective in their effect. Among the crop geometric strategies, the highest uptake of P of 12.3 kg/ha resulted under C_4, while the lowest uptake of P of 10.5 kg/ha resulted under C_1. C_3 has shared statistical parity with C_4. The interaction of hydrogel levels and crop geometric strategies influenced the P uptake in stover was found to be non-significant.

c. Total phosphorus uptake (kg/ha)

In the first year (2022) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum total uptake of P of 27.0 kg/ha resulted under H_3, while the minimum total P of 20.9 kg/ha resulted under H_1. The impact of crop geometric strategies was statistically significant. Among the crop geometric strategies, the maximum total uptake of P of 25.7 kg/ha resulted under C_4, while the minimum total uptake of P of 22.1 kg/ha resulted under C_1. C_3 has shared statistical parity with C_4. The interaction of both factors has been found to be non-significant in the enhancement of the total uptake of P.

In the second year (2023) of study, the effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest total uptake of P of 28.4 kg/ha resulted under H_3, while the lowest total uptake of P of 22.2 kg/ha resulted under H_1. The impact of crop geometric strategies was found statistically significant. Among the crop geometric strategies, the maximum total uptake of P of 26.9 kg/ha resulted under C_4, whereas the lowest total uptake of P of 23.4 kg/ha resulted under C_1. C_3 has shared statistical parity with C_4. The interaction of both factors was non-significant on the total P uptake.

Regarding the mean data, effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest total P uptake of 27.7 kg/ha was recorded under H_3, while the lowest total uptake of P of 21.6 kg/ha resulted under H_1. The effect of crop geometric strategies was significantly evident on the total P uptake. Among the crop geometric strategies, the maximum total uptake of P of 26.3 kg/ha resulted under C_4, while the minimum total uptake of P of 22.8 kg/ha was recorded under C_1. C_3 has shared statistical parity with C_4. The interaction of both factors had a significant impact on the enhancement in the total uptake of P by the plant.

4.2.2.1.3. Total uptake of potassium (K) (kg/ha)

a. Potassium uptake (kg/ha) in grains

In the first year (2022) of study, the influence of hydrogel levels was found statistically significant. Th maximum uptake of K of 18.9 kg/ha resulted under H_3, while the minimum uptake of K of 15.8 kg/ha resulted under H_1. The impact of crop geometric strategies was also found statistically significant. Among the crop geometric strategies, the highest uptake of K of 18.2 kg/ha resulted under C_4, while the lowest uptake of K of 16.3 kg/ha resulted under C_1. The C_2 and C_3 have shared statistical parity with C_4. The interaction of both factors has shown a non-significant influence on the uptake of K in the grain.

In the second year (2023) of study, the effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest uptake of K of 19.8 kg/ha resulted under H_3, while the lowest uptake of K of 16.7 kg/ha resulted under H_1. H_2 was found to be statistically at par with H_3. The impact of crop geometric strategies was also found statistically significant. Among the crop geometric strategies, the maximum grain uptake of K of 19.1 kg/ha resulted under C_4, while the maximum grain K uptake of 17.5 kg/ha resulted under C_1. The C_2 and C_3 have shared statistical parity with C_4. The interaction effect of both factors was found statistically non-significant.

In the mean data, effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum grain uptake of K of 19.3 kg/ha resulted under H_3, while H_1 resulted in the minimum grain uptake of K of 16.3 kg/ha. H_2 was found to be statistically at par with H_3. The crop geometric strategies were significantly effective in their effect. Among the crop geometric strategies, the maximum grain uptake of K of 18.7 kg/ha resulted under C_4, while the minimum uptake of K in grains of 16.9 kg/ha resulted under C_1. The C_2 and C_3 have shared statistical parity with C_4. The interaction of hydrogel levels and crop geometric strategies significantly improved the K uptake in grains.

b. Potassium uptake (kg/ha) in stover

In the first year (2022) of study, the impact of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest uptake of K of 82.1 kg/ha resulted under H_3, while the minimum uptake of K of 74.3 kg/ha resulted under H_1. H_2 was found to be statistically at par with H_3. The crop geometric strategies were significantly effective in their effect. Among the crop geometric strategies, the highest uptake of K of 80.0 kg/ha resulted under C_4, while the lowest uptake of K of 76.1 kg/ha resulted under C_1. C_3 has shared statistical parity with C_4. The impact of the interaction of both factors was statistically non-significant on the improvement of the K uptake in stover.

In the second year (2023) of study, influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest K uptake in stover of 90.0 kg/ha was recorded under H_3, while the lowest K uptake in stover of 82.1 kg/ha was recorded under H_1. H_2 was found to be statistically at par with H_3. The crop geometric strategies were significant in their effect on the K uptake in the stover. Among the crop geometric strategies, the highest uptake of K of 87.8 kg/ha resulted under C_4, while the lowest uptake of K of 83.4 kg/ha resulted under C_1. C_3 has shared statistical parity with C_4. The interaction of both factors showed a significant impact in enhancing the stover K uptake.

In the mean data, the effect of hydrogel levels on the K uptake was significantly evident. Among the hydrogel levels, the maximum K uptake in the stover of 85.9 kg/ha was recorded under H_3, while H_1 resulted in the minimum uptake of K of 78.2 kg/ha. H_2 was found to be statistically at par with H_3. The effect of crop geometric strategies was found statistically significant. Among the crop geometric strategies, the highest uptake of K of 83.9 kg/ha resulted under C_4, while the lowest uptake of K of 79.8 kg/ha resulted under C_1. C_3 has shared statistical parity with C_4. The interaction of both factors has been found to be non-significant in the enhancement of K uptake in the stover.

c. Total potassium uptake (kg/ha):

In the first year (2022) of study, the impact of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum uptake of K of 101.0 kg/ha resulted under H_3, while the minimum K uptake of 90.1 kg/ha resulted under H_1. The crop geometric strategies were statistically significant in their effect. Among the crop geometric strategies, the maximum uptake of K of 98.3 kg/ha resulted under C_4, while the minimum total uptake of K of 92.4 kg/ha resulted under C_1. C_3 has shared statistical parity with C_4. The interaction effect of both factors has a non-significant effect on the total uptake of K.

In the second year (2023) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum total uptake of K of 109.5 kg/ha resulted under H_3, whereas the minimum total uptake of K of 98.8 kg/ha resulted under H_1. The impact of crop geometric strategies was found statistically significant. Among the crop geometric strategies, the maximum total uptake of K of 106.9 kg/ha resulted under C_4, while the minimum total uptake of K of 100.9 kg/ha resulted under C_1. The impact of the interaction of both factors was non-significant on the total K uptake.

Regarding the mean data, the effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum total uptake of K of 105.3 kg/ha resulted under H_3, while the minimum total uptake of K of 94.4 kg/ha resulted under H_1. The impact of crop geometric strategies was significantly evident. Among the crop geometric strategies, the maximum total uptake of K of 102.6 kg/ha resulted under C_4, whereas the minimum total uptake of K of 96.6 kg/ha resulted under C_1. The interaction of both factors has significantly influenced the total K uptake in the plant.

Nutrient uptake is the process by which plant cells take nutrients and help assimilate them into chemical compounds. Plants can obtain nutrients from the atmosphere, but maximum nutrient requirements are fulfilled from the soil. The nutrients are available to the plants in the soil naturally or applied in the form of fertilizers as per the requirements of the crop grown. The available pool of nutrients in the soil is not entirely used by the plant but can also lost in the form of leaching, runoff etc. Out of various factors that affect nutrient uptake, soil water/ moisture content is the key aspect. The lack of water or moisture will hamper the mass flow. The hindrance of the mass flow interrupts nutrient absorption from soil to plants which can have a significant influence on the development of roots. The difference in the moisture regimes in the control and hydrogel-applied plots might have resulted in more nutrient uptake **(Fitriatin *et al.,* 2021).**

The nutrient uptake of N, P and K has improved with the enhancement in the hydrogel dose **(Manish *et al.,* 2023).** Hydrogel application has increased nutrient uptake by preventing nutrient losses. The amendment might have supplied water for the growth of plants and eventually the superior leaf area index and chlorophyll content. This could have been attributed to the prolonged duration of stomata opening and better CO_2 fixation that led to enhanced nutrient uptake **(Singh *et al.,* 2017).** The increment in the nutrient uptake might be because of the nutrient-holding property of hydrogel for prolonged duration and contributed to higher accessibility of nutrients in the soil as well as better synchrony in the release of nutrients and uptake by the plant. The hydrogel might have prevented the K losses, which is essential for

4.31. Influence of different hydrogel levels and crop geometric strategies on the N uptake (kg/ha) of spring maize.

S.no	Factors	N uptake in the grain (kg/ha)			N uptake in the stover (kg/ha)			Total N uptake (kg/ha)		
		2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
	Hydrogel levels									
1	Without hydrogel application in soil	53.5	58.7	56.1	36.9	44.5	40.7	90.4	103.1	96.8
2	With hydrogel application in the soil at1.5 kg/ha	56.4	62.1	59.2	40.4	47.9	44.2	96.8	110.0	103.4
3	With hydrogel application in the soil at 3 kg/ha	60.0	65.5	62.7	44.5	52.0	48.4	104.4	117.5	111.0
	CD (at p≤ 0.05)	4.2	4.4	4.0	5.2	5.5	5.4	2.8	4.5	3.3
	SEm (±)	1.0	1.1	0.993	1.3	1.4	1.3	0.714	1.1	0.820
	Crop geometric strategies									
1	Normal spacing (70 × 25 cm)	54.4	60.1	57.2	38.5	45.9	42.2	92.9	106.0	99.5
2	Paired-row spacing (55 - 85 × 25 cm)	56.8	61.3	59.1	40.1	47.6	43.9	96.8	108.9	102.9
3	Normal spacing (70 × 25 cm) with the seed capsule	56.8	62.8	59.8	41.2	48.7	45.0	97.9	111.5	104.7
4	Paired-row spacing (55 - 85 × 25 cm) with the seed capsule	58.6	64.1	61.4	42.6	50.2	46.4	101.1	114.3	107.7
	CD (at p≤ 0.05)	2.7	2.9	2.4	2.3	2.1	2.2	2.9	3.5	2.8
	SEm (±)	0.892	0.970	0.807	0.762	0.690	0.720	0.982	1.2	0.947
	A x B	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.32. Influence of different hydrogel levels and crop geometric strategies on the P uptake (kg/ha) of spring maize.										
S.no	**Factors**	**P uptake in the grain (kg/ha)**			**P uptake in the stover (kg/ha)**			**Total P uptake (kg/ha)**		
		2022	**2023**	**Mean**	**2022**	**2023**	**Mean**	**2022**	**2023**	**Mean**
	Hydrogel levels									
1	Without hydrogel application in soil	11.4	12.1	11.8	9.5	10.1	9.8	20.9	22.2	21.6
2	With hydrogel application in the soil at1.5 kg/ha	12.8	13.5	13.1	11.1	11.7	11.4	23.8	25.1	24.5
3	With hydrogel application in the soil at 3 kg/ha	14.3	15.0	14.7	12.7	13.3	13.0	27.0	28.4	27.7
	CD (at p≤ 0.05)	1.3	1.5	1.4	1.9	1.9	1.9	1.4	1.3	1.3
	SEm (±)	0.316	0.381	0.347	0.463	0.476	0.469	0.336	0.310	0.321
	Crop geometric strategies									
1	Normal spacing (70 × 25 cm)	11.9	12.7	12.3	10.2	10.8	10.5	22.1	23.4	22.8
2	Paired-row spacing (55 - 85 × 25 cm)	12.7	13.4	13	10.9	11.5	11.2	23.6	24.9	24.3
3	Normal spacing (70 × 25 cm) with the seed capsule	13.1	13.8	13.5	11.3	11.9	11.6	24.4	25.7	25.0
4	Paired-row spacing (55 - 85 × 25 cm) with the seed capsule	13.6	14.3	14.0	12.0	12.6	12.3	25.7	26.9	26.3
	CD (at p≤ 0.05)	1.1	0.960	1.0	1.0	1.1	1.0	1.6	1.53	1.6
	SEm (±)	0.364	0.321	0.341	0.336	0.357	0.346	0.538	0.511	0.523
	A x B	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.33. Influence of different hydrogel levels and crop geometric strategies on the K uptake (kg/ha) of spring maize.										
S.no	**Factors**	**K uptake in the grain (kg/ha)**			**K uptake in the stover (kg/ha)**			**Total K uptake (kg/ha)**		
		2022	**2023**	**Mean**	**2022**	**2023**	**Mean**	**2022**	**2023**	**Mean**
	Hydrogel levels									
1	Without hydrogel application in soil	15.8	16.7	16.3	74.3	82.1	78.2	90.1	98.8	94.4
2	With hydrogel application in the soil at1.5 kg/ha	17.3	18.3	17.8	78	85.5	81.7	95.2	103.7	99.5
3	With hydrogel application in the soil at 3 kg/ha	18.9	19.8	19.3	82.1	90.0	85.9	101.0	109.5	105.3
	CD (at p≤ 0.05)	1.4	1.7	1.5	5.7	5.6	5.6	5.0	4.9	5.0
	SEm (±)	0.335	0.411	0.366	1.4	1.38	1.39	1.24	1.23	1.23
	Crop geometric strategies									
1	Normal spacing (70 × 25 cm)	16.3	17.5	16.9	76.1	83.4	79.8	92.4	100.9	96.6
2	Paired-row spacing (55 - 85 × 25 cm)	17.1	18.1	17.6	77.6	85.3	81.5	94.7	103.5	99.1
3	Normal spacing (70 × 25 cm) with the seed capsule	17.6	18.5	18.0	78.7	86.3	82.5	96.3	104.8	100.5
4	Paired-row spacing (55 - 85 × 25 cm) with the seed capsule	18.2	19.1	18.7	80.0	87.8	83.9	98.3	106.9	102.6
	CD (at p≤ 0.05)	1.1	1.0	1.0	2.1	2.0	2.0	2.2	1.9	2.1
	SEm (±)	0.278	0.349	0.354	0.707	0.670	0.679	0.748	0.660	0.691
	A x B	NS	NS	NS	NS	NS	NS	NS	NS	NS

good root growth, elongation and proliferation. Thereby aiding the water and nutrient extraction from the soil.

Nutrient uptake has abridged under poor soil moisture conditions, it might be because of the deprived translocation, absorption and plant water relations **(Rajavarthini & Kalyanasundaram, 2022).** Similar outcomes were reported by **Eissa & Negim (2019); Moser *et al.* (2006).** Hydrogel permits nutrient holding at the exchange site and releases them at the right time for plant uptake. This progression condenses the volatilization of NH_3 and nutrient leaching, enhancing nutrient uptake and enabling superior efficiency of nutrient use. This might have led to increased nutrient uptake in the case of the hydrogel-applied treatment and made a difference from the control **(El-Asmar *et al.,* 2017; Xu *et al.,* 2015).** Hydrogel application diminishes nutrient losses and enhanced water consumption efficiency, eventually increasing nutrient uptake **(Dehkordi, 2016; Abobatta, 2018).**

The biofertilizer application has shown a tremendous impact on nutrient uptake when compared to the control (**Chimate *et al.,* 2023).** The NPK biofertilizer consortium comprises all kinds of biofertilizers of macronutrients like rhizobium, azotobacter, azosprillum, phosphobacteria, and potash solubilizing bacteria. The combined effect of biofertilizers might have helped in enhancing the macronutrient uptake by the crop **(Tiwari *et al.,* 2018; Tanwar *et al.,* 2003; Djajadi *et al.,* 2019; Yadav *et al.,* 2021).** The N biofertilizers increased N availability by effectively converting the non-available form of N to the available form (**Talwar *et al.,* 2017**). Similarly, the phosphobacteria might have helped in the easy dilution of the P in the soil and making the P more accessible to plants eventually augmented the P uptake **(Dhakal *et al.,* 2016; Thenua &Ravindra, 2011).** Similar outcomes were reported by **Kant *et al.* (2017)**; **Meena *et al.* (2013).** The biofertilizer consortium could have enhanced the nitrogenase and nitrate-reductase enzyme activity in the soil which resulted in more biological N fixation **(Patil *et al.,* 2018; Gohil *et al*., 2021)**. The humic acid also showed an increment in nutrient uptake **(Daur & Bakhashwain, 2013).**

4.2.2.2. Grain protein content (%)

The data concerning the different hydrogel levels and crop geometric strategies on grain protein content (%) is depicted in tables 4.33. In the first year (2022) of the study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum grain protein content of 10.4% was obtained by H_3, while the minimum grain protein content of 8.1% was obtained by H_1. The crop geometric strategies were significantly effective in the improvement of the protein content. Among the crop geometric strategies, the highest grain protein content of 9.6% was obtained by C_4, while the lowest protein content of 8.7% was obtained by C_1. C_3 has shared statistical parity with C_4. The interaction effect of hydrogel levels and crop geometric strategies has found to be non-significant in the protein content in the grain.

In the second year (2023) of study, the influence of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum grain protein content of 12.3% was obtained by H_3, while the minimum grain protein content of 10.1 % was obtained by H_1. The crop geometric strategies were significantly effective in their effect. Among the crop geometric strategies, the highest grain protein content of 11.8% was obtained by C_4, while the lowest protein content of 10.5 % was obtained by C_1. The interaction of both factors has shown a non-significant impact on the protein content in the grain.

Regarding the mean data, the effect of hydrogel levels was found statistically significant. Among the hydrogel levels, the maximum grain protein content of 11.3% was obtained by H_3, while the minimum protein content of 9.1% in the grain was obtained by H_1. The impact of crop geometric strategies was found statistically significant. Among all the crop geometries, the highest grain protein content of 10.7 % was obtained by C_4, while the lowest grain protein content of 9.6 % was obtained by C_1. The interaction of both factors has been found to have a non-significant impact on the grain protein content of maize.

The protein content was amplified with the enhancement in the dose of hydrogel. The hydrogel application might have induced plant vigour and enhanced growth by the increase of metabolic activities, enhanced α-amylase and protease activity with the better accessibility of nutrients as well as moisture **(Meena *et al.,* 2020)**. The polymer could have up-regulated the protease and α-amylase activity in the plant that eventually enhanced macronutrient content in grain, straw and leaf as well as grain protein content (**Manish *et al.,* 2023; Yu *et al.,* 2012 and Kumar *et al*., 2022).** Analogous outcomes were reported by **Singh *et al.* (2017)**. The conjoint employment of hydrogel, inorganic fertilizers, biofertilizers and humic acid might have improved the accessibility of the nutrient to the plant and consequently enhanced the protein content of the spring maize **(Meena *et al.,* 2013).** The paired row spacing which might have enabled the better use of resources by reducing the competition and led to higher uptake and nutrient translocation of to sink **(Nand, 2015).**

4.2.2.3. Grain appearance score (1-3)

The data regarding the impact of different hydrogel levels and crop geometric strategies on the grain appearance score (1-3) is depicted in table 4.33. In the first year (2022) of study, the impact of hydrogel levels was found statistically significant. Among the hydrogel levels, the highest grain appearance score of 2.4 out of 3 was obtained by H_3, while the lowest grain appearance score of 1.3 out of 3 was obtained by H_1. The impact of crop geometric strategies

Table.4.34. Influence of different hydrogel levels and crop geometric strategies on the protein content (%) and grain appearance score of spring maize.

S.no	Factors	Protein content (%)			Grain appearance score		
		2022	2023	Mean	2022	2023	Mean
	Hydrogel levels						
1	Without hydrogel application in soil	8.1	10.1	9.1	1.3	1.8	1.5
2	With hydrogel application in the soil at1.5 kg/ha	9.0	11.1	10.0	1.9	2.1	2.0
3	With hydrogel application in the soil at 3 kg/ha	10.4	12.3	11.3	2.4	2.8	2.6
	CD (at p≤ 0.05)	0.323	0.369	0.340	0.219	0.158	0.110
	SEm (±)	0.080	0.091	0.084	0.054	0.039	0.027
	Crop geometric strategies						
1	Normal spacing (70 × 25 cm)	8.7	10.5	9.6	1.6	2.0	1.8
2	Paired-row spacing (55 - 85 × 25 cm)	9.1	11.0	10.0	1.8	2.1	1.9
3	Normal spacing (70 × 25 cm) with the seed capsule	9.2	11.3	10.2	2.0	2.3	2.1
4	Paired-row spacing (55 - 85 × 25 cm) with the seed capsule	9.6	11.8	10.7	2.1	2.5	2.3
	CD (at p≤ 0.05)	0.404	0.398	0.356	0.143	0.195	0.109
	SEm (±)	0.135	0.133	0.119	0.048	0.065	0.036
	A x B	NS	NS	NS	NS	NS	NS

on the grain appearance score was found statistically significant. Among the crop geometric strategies, the highest grain appearance score of 2.1 out of 3 was obtained by C_4, while the lowest grain appearance score of 1.6 out of 3 was obtained by C_1. The impact of the interaction of both the factors had a non-significant influence on the grain appearance score.

In the second year (2023) of study, influence of hydrogel levels was found statistically significant Among the hydrogel levels, highest grain appearance score of 2.8 out of 3 was obtained by H_3, while the lowest grain appearance score of 1.8 out of 3 was obtained by H_1. The crop geometric strategies were significantly effective in their effect on the grain appearance score. Among all the crop geometries, the highest grain appearance score of 2.5 out of 3 was obtained by C_4, while the grain appearance score of 2.0 out of 3 was obtained by C_1. The interaction of both factors has shown a non-significant effect on the improvement of the grain appearance score.

Regarding the mean data, effect of hydrogel levels on the grain appearance score was found significant. Among the hydrogel levels, highest grain appearance score of 2.6 out of 3 was obtained by H_3, whereas the lowest grain appearance score of 1.5 out of 3 was obtained by H_1. The effect of crop geometric strategies was found statistically significant. Among the crop geometric strategies, the highest grain appearance score of 2.3 out of 3 was obtained by C_4, while the lowest grain appearance score of 1.8 out of 3 was obtained by C_1. The impact of the interaction of both factors had a non-significant influence on the grain appearance score.

The grain appearance score echoes the condition of grains during the grain filling and hardening stage. The weather fluctuations particularly high temperature extremes affect the grain quality. The properly filled grains with sheen and devoid of stress during the grain filling and hardening stage can score high, the vice versa with the one which scores low. The grain appearance score depends upon the characteristics like size, shape and luster of grain. The grain with a high grain appearance score which resulted in uniform size, shape and glossy luster might be because of high protein content in the grains **(Kumar *et al.,* 2013).** The vitreous endosperms consist of high gliadin content that resulted in sophisticated adhesion of the protein matrix on the starch granules during the grain desiccation which might have caused a compact endosperm shape. The enhanced protein content with the increased availability of nutrients prior to the anthesis could have developed a better network around the starch granules which led to a superior glossy appearance of the grain **(Samson *et al.,* 2005).** The high-scoring grains are much preferred during the processing because of their glossy luster, attractive size and shape.

4.3. Impact of the different hydrogel levels and crop geometric strategies on the monetary parameters of spring maize

The monetary parameters of treatments comprised the cultivation cost, gross return, net return as well as the B: C ratio as depicted in table 4.34, while the calculation of fixed, variable cost and overall cost of cultivation was included in appendix 2-4.

4.3.1. Cost of cultivation

The cultivation cost consists of two types of costs i.e., fixed cost and variable cost. The fixed cost is a common expenditure involved for all the treatments. The fixed cost of Rs. 35659/ha was involved for all treatments. The variable cost is the expenditure that varies due to the employment of different treatments as per the treatment combination i.e., seed capsules, hydrogel and labour cost for irrigation and capsule filling. The variable costs of different treatments are shown in appendix no. 2-4. In the year 2022, among the 12 treatments the lowest expenditure of Rs. 49159/ha was recorded under H_3C_1 (Hydrogel 3 kg/ha + normal spacing (70 × 25 cm)) and H_3C_2 (Hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)). While the highest expenditure of Rs. 59788/ha was recorded under H_1C_3 (Hydrogel 0 kg/ha + normal spacing (70 × 25 cm) with seed capsule) and H_1C_4 (Hydrogel 0 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule). In the year 2023, among the 12 treatments the lowest expenditure of Rs. 45559/ha was recorded under H_2C_1 (Hydrogel 1.5 kg/ha + normal spacing (70 × 25 cm)), H_2C_2 (Hydrogel 1.5 kg/ha + paired row spacing (55-85 × 25 cm)), H_3C_1 (Hydrogel 3 kg/ha + normal spacing (70 × 25 cm)) and H_3C_2 (Hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)). While the highest expenditure of Rs. 54388/ha was recorded under H_1C_3 (Hydrogel 0 kg/ha + normal spacing (70 × 25 cm) with seed capsule) and H_1C_4 (Hydrogel 0 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule).

4.3.1. Gross return (Rs/ha):

Among all the treatments, the highest gross return of Rs.183480/ha was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) followed by H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with the seed capsule) with Rs. 180360/ha in 2022. Whereas in 2023, the highest gross return of Rs. 205160/ha was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) followed by H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule) with Rs.199405/ha. The lowest gross return of Rs.131853/ha was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) followed by H_1C_3 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm) with seed capsule) with Rs. 135967/ha in 2022, whereas in 2023, the lowest gross return of Rs. 144926/ha was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 ×

Table. 4.35. Influence of different hydrogel levels and crop geometric strategies on the monetary parameters of the spring maize.										
S. no	**T. N.**	**T.C.**	**Cost of cultivation (₹/ha)**		**Gross return (₹/ha)**		**Net return (₹/ha)**		**B:C ratio**	
			2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
1	T_1	H_1C_1	51859	46459	131853	144926	79994	98467	1.54	2.12
2	T_2	H_1C_2	51859	46459	143651	147935	91792	101476	1.77	2.18
3	T_3	H_1C_3	59788	54388	135967	154017	76178	99629	1.27	1.83
4	T_4	H_1C_4	59788	54388	153258	158006	93470	103618	1.56	1.91
5	T_5	H_2C_1	50959	45559	147536	164416	96577	118857	1.90	2.61
6	T_6	H_2C_2	50959	45559	158565	169386	107606	123827	2.11	2.72
7	T_7	H_2C_3	58888	53488	162133	174618	103245	121130	1.75	2.26
8	T_8	H_2C_4	58888	53488	168902	179654	110014	126166	1.87	2.36
9	T_9	H_3C_1	49159	45559	165213	183382	116054	137823	2.36	3.03
10	T_{10}	H_3C_2	49159	45559	174036	191557	124877	145998	2.54	3.20
11	T_{11}	H_3C_3	57088	53488	180360	199405	123272	145916	2.16	2.73
12	T_{12}	H_3C_4	57088	53488	183480	205160	126392	151672	2.21	2.84

25 cm)) followed by H_1C_2 (hydrogel 0 kg/ha + paired row spacing (55-85 × 25 cm)) with Rs. 147935/ha.

4.3.2. Net return (Rs/ha):

Among all the treatments, the highest net return of Rs.126392/ha was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) followed by H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm) with seed capsule) with Rs. 123272/ha in 2022. Whereas in 2023, the highest net return of Rs.151672/ha was recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) followed by H_3C_2 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)) with Rs.145998/ha. The lowest net return of Rs.76178/ha was recorded under H_1C_3 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm) with seed capsule) followed by H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) with Rs.79994/ha in 2022. In 2023, the lowest net return of Rs.98467/ha was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) followed by H_1C_3 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm) with seed capsule) with Rs.99629/ha.

4.3.3. Benefit: Cost ratio (B: C ratio):

In 2022, the highest B: C ratio of 2.54 was obtained by H_3C_2 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)) followed by H_3C_1 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm)) with 2.36, whereas in 2023, the highest B: C ratio of 3.20 was recorded under H_3C_2 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)) followed by H_3C_1 (hydrogel 3 kg/ha + normal spacing (70 × 25 cm)) with 3.03. In 2022, the minimum B: C ratio of 1.27 was recorded under H_1C_3 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm) with the seed capsule) followed by H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) with 1.54. whereas in 2023, the same treatment H_1C_3 obtained the lowest B: C ratio of 1.83 followed by H_1C_4 (hydrogel 0 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) with 1.91.

The application of hydrogel and seed capsules has increased the cost of cultivation up to an extent over the control. Despite the increase in the cost of cultivation, the application of hydrogel and seed capsules was found efficacious in accruing the maximum gross and net returns over the control. The cost of seed capsules has shown an impact on the benefit-cost ratio up to an extent than the hydrogel. The treatment with hydrogel at 3 kg/ha dosage and without seed capsules i.e., H_1C_1 and H_3C_2, obtained the maximum benefit-cost ratio when compared to the H_3C_3 and H_3C_4. The obtained results are supported by the outcomes of **Rani *et al.* (2006); Kumar & Shankaralingappa (2017); Srilathavani *et al.* (2020); Kalita *et al.* (2019); Sagar *et al.* (2020).**

CHAPTER - V
SUMMARY AND CONCLUSION

CHAPTER- V

SUMMARY AND CONCLUSIONS

A field experiment was executed to assess the influence of different levels of hydrogel and crop geometric strategies on the performance of spring maize at Lovely Professional University, Phagwara during the spring seasons of 2022 and 2023. The experiment was executed in the split-plot design with three replications. Different hydrogel levels were assigned to the main plots and crop geometric strategies to the sub-plots. The main plot comprised of three levels of hydrogel i.e., 0 (0 kg/ha) (control), 50% (1.5 kg/ha) and 100% (3kg/ha). Each main plot comprised of four crop geometric strategies i.e., normal spacing (70 x 25 cm); paired-row spacing (55-85 x 25 cm); normal spacing with the seed capsule (70 x 25 cm) and paired-row spacing (55-85 x 25 cm) with the seed capsule.

In this study, an approach was initiated to comprehend the impact of irrigation and crop geometric strategies on the growth as well as yield of spring maize. Also, the research was envisioned to evaluate the role of different hydrogel levels and crop geometric strategies on the improvement of quality parameters like nutrient uptake, available soil nutrients at harvest, moisture studies, grain protein content and grain appearance score of spring maize. A brief summary of the experimental findings are given below.

1. The employment of different hydrogel levels and crop geometric strategies have favoured plant growth of spring maize at different growth intervals. In 2022, the highest plant height of 15.4 cm, 67.6 cm, 134.0 cm and 174.0 cm; whereas in 2023, the highest plant height of 22.6 cm, 82.9 cm, 163.7 cm and 210.3 cm were recorded at 25, 50, 75 and 100 DAS respectively by the application of the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). The lowest plant height at all the growth intervals in both years was recorded under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).
2. In 2022, the highest leaf count of 7.8, 10.4, 16.1 and 14.3; while in 2023, the highest leaf count of 8.6, 11.2, 16.6 and 15.1 was obtained at the 25, 50, 75 and 100 DAS, respectively. Maximum number of leaves per plant were recorded under the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). Whereas, the minimum number of leaves per plant resulted under H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).
3. In 2022, a wider stem girth of 3.4 cm, 6.0 cm, 8.1 cm and 10.0 cm; while in 2023, a wider stem girth of 3.7 cm, 7.0 cm, 8.9 cm and 10.8 cm was obtained at 25, 50, 75 and 100 DAS

respectively. The wider stem girth was obtained by the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). Whereas, at all growth intervals, the narrower stem girth was recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).

4. In 2022, a wider stem diameter of 1.1cm, 1.9 cm, 2.9 cm and 3.2 cm; while in 2023, a wider stem girth of 1.2 cm, 2.2 cm, 2.8 cm and 3.4 cm was obtained at 25, 50, 75 and 100 DAS respectively. The wider stem girth was obtained by the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). Whereas, at all growth intervals, the narrower stem girth was recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).
5. The highest cob count per plant of 2.2 and 2.3 was recorded under the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) in 2022 and 2023 respectively. The lowest cob count per plant of 1.0 in both 2022 and 2023 was recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).
6. The longest cob length of 20.8 cm and 21.6 cm was obtained by the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) in 2022 and 2023 respectively. Whereas, the shortest cob length of 15.6 cm and 16.3 cm was obtained under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) in 2022 and 2023 respectively.
7. The cob weight with the husk and without the husk was significantly improved under the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). An increment in the cob weight with husk by 23.5% and 21.8% was recorded over the control in 2022 and 2023 respectively. Similarly, an increase in the cob weight without husk by 31.7 % and 28.1% was recorded in 2022 and 2023 respectively compared to the control.
8. The highest row count per cob of 13.1 and 13.8 was obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) in 2022 and 2023 respectively. While, the lowest row count per cob of 9.8 and 10.4 was obtained by the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) in 2022 and 2023 respectively.
9. The maximum grain count per row of the cob of 31.3 and 33.6 was obtained by H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) in 2022 and 2023 respectively. Whereas, the minimum number of grains per row of the cob of 27.5 and 29.8 was obtained by the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) in 2022 and 2023 respectively.

10. The grain count per cob was significantly influenced by the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). An upsurge in the grain count per cob by 34.5% and 32.8% was recorded in 2022 and 2023 respectively over the control.
11. The highest seed index of 31.9 g and 32.4 g was recorded under the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) in 2022 and 2023 respectively. The lowest seed index of 30.1 g and 30.5g was recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) in 2022 and 2023 respectively.
12. The trend that was pragmatic in the yield contributing attributes was also observed in the yield parameters like grain, stover, biological yield and harvest index.
13. The significantly higher grain yield was obtained by the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). An increase in the grain yield by 28.12% and 29.34% was recorded in 2022 and 2023 respectively when compared to the control.
14. Similar to the grain yield the same treatment resulted in superior stover yield. An increase in the stover yield by 24.48% and 19.96% was recorded in 2022 and 2023 respectively when compared to the control.
15. The maximum biological yield of 25.9 t/ha and 28.1 t/ha was obtained by the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) in 2022 and 2023 respectively. Whereas, a minimum biological yield of 20.6 t/ha and 21.6 t/ha was obtained by the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)) in 2022 and 2023 respectively.
16. The highest harvest index of 29.91% in 2022 and 30.06% in 2023 was recorded under the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). Whereas, the lowest harvest index of 28.17% in 2022 and 28.51% in 2023 was recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).
17. The highest available soil macronutrients like N, P and K at the harvest were recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). While the lowest available soil macronutrients were recorded under H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). The more nutrient uptake in best-performed treatments has effectively utilized the nutrients and depleted the soil nutrient status.

18. The employment of hydrogel had a substantial influence on the no. of irrigations given during the cropping season. The main plots with 3 kg/ha hydrogel were given 8 irrigations in 2022 and 4 irrigations in 2023. Whereas, the main plots with (0 kg/ha) hydrogel were given 13 irrigations in 2022 and 7 in 2023. In 2022, the application of hydrogel at the rate of 3 kg/ha saved 5 irrigations compared to 0 kg/ha. While in 2023, the same dose of hydrogel saved 3 irrigations compared to the 0 kg/ha.
19. The hydrogel application significantly affected the irrigation intervals and enhanced the time between two irrigations by holding the water for prolonged durations. The longest average irrigation interval of 11.8 days and 18.8 days were recorded in 2022 and 2023 respectively with the application of 3 kg/ha of hydrogel, while the shortest average irrigation intervals of 7.6 and 11.9 were recorded in 2022 and 2023 respectively under the 0 kg/ha of hydrogel.
20. The highest N uptake in the grains as well as stover was obtained by the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) followed by the treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 x 25 cm) with the seed capsule). Whereas, the lowest N uptake in the grains as well as stover was obtained by the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).
21. The maximum P uptake in the grains as well as stover was recorded under the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). While, the minimum P uptake in grains and stover was recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).
22. Similar to the N as well as P uptake, the maximum K uptake in the grains and stover was recorded under the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) followed by the treatment H_3C_3 (hydrogel 3 kg/ha + normal spacing (70 x 25 cm) with the seed capsule). While, the minimum K uptake in grains and stover was recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).
23. The protein content was significantly improved by the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). An increase in the protein content by 18.1% and 25.4% was recorded in 2022 and 2023 respectively compared to the control. While, the minimum protein content was recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).
24. The highest grain appearance score of 2.7 in 2022 and 3.0 in 2023 was recorded under the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). Whereas, the poorest grain appearance score of 1.0 in 2022 and 1.6 in 2023 was

recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)). The cost of cultivation varied under the different treatment combinations.

25. Cost of cultivation varied under various treatment combinations. In 2022, the lowest expenditure of Rs. 49159/ha was found under H_3C_1 (Hydrogel 3 kg/ha + normal spacing (70 × 25 cm)) and H_3C_2 (Hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)). While the highest expenditure of Rs. 59788/ha was recorded under H_1C_3 (Hydrogel 0 kg/ha + normal spacing (70 × 25 cm) with seed capsule) and H_1C_4 (Hydrogel 0 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule). In the year 2023, among the 12 treatments the lowest expenditure of Rs. 45559/ha was recorded under H_2C_1 (Hydrogel 1.5 kg/ha + normal spacing (70 × 25 cm)), H_2C_2 (Hydrogel 1.5 kg/ha + paired row spacing (55-85 × 25 cm)), H_3C_1 (Hydrogel 3 kg/ha + normal spacing (70 × 25 cm)) and H_3C_2 (Hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)). While the highest expenditure of Rs. 54388/ha was recorded under H_1C_3 (Hydrogel 0 kg/ha + normal spacing (70 × 25 cm) with seed capsule) and H_1C_4 (Hydrogel 0 kg/ha + paired row spacing (55-85 × 25 cm) with seed capsule).
26. Among all the treatments, the highest gross as well as the net return of Rs.1,83,480/ha and Rs.1,26,392/ha, was recorded under the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule) in 2022. The lowest gross as well as the net returns of Rs. 1,31,853/ha and Rs. 76,178/ha, were recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)), H_1C_3 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm) with seed capsule) respectively. In 2023, the highest gross as well as the net return of Rs.2,05,160/ha and Rs.1,51,672/ha, was recorded under the treatment H_3C_4 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm) with the seed capsule). The lowest gross as well as the net returns of Rs. 144926/ha and Rs. 98,467/ha, were recorded under the treatment H_1C_1 (hydrogel 0 kg/ha + normal spacing (70 × 25 cm)).
27. The highest benefit-cost ratio of 2.54 in 2022 and 3.20 in 2023 was recorded under the treatment H_3C_2 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)). While, the treatment H_1C_3 (hydrogel 0 kg/ha + normal spacing (70 ×25 cm) with the seed capsule) resulted in the lowest benefit-cost ratio of 1.27 and 1.83 in 2022 and 2023 respectively.

Conclusion

The experimental findings of the current study interpret a productive influence of doses of hydrogel and crop geometric strategies on the enhancement of spring maize performance. The combination of hydrogel dose of 3 kg/ha and paired row spacing (55-85 × 25 cm) with the seed capsule i.e., H_3C_4 impacted growth parameters like plant height (cm), number of leaves, stem girth (cm) and stem diameter (cm), yield and quality parameters. The hydrogel application at 3 kg/ha has prolonged the moisture retention period, further reduced the need of irrigation and the irrigation counts during the cropping season over the control. No improvement in the soil parameters was recorded when treatments were employed. The quality parameters like N, P and K nutrient uptake; grain protein content (%) and grain appearance score were improved under H_3C_4. The monetary advantage of all the treatments of the experiment was recorded. Hence, it can be concluded that hydrogel dose of 3 kg/ha and paired row spacing (55-85 × 25 cm) with the seed capsule i.e., H_3C_4 had a promising impact in attaining advanced growth and productivity of spring maize. At the same time, the treatment H_3C_2 (hydrogel 3 kg/ha + paired row spacing (55-85 × 25 cm)) was found profitable from the farmer's point of view. The application of hydrogel at 3 kg/ha might have enhanced soil moisture retention by absorbing and gradually releasing water and ensuring consistent moisture availability for maize. Thereby reduced drought stress, promoted growth and yield attributes; improved nutrient uptake efficiency. Paired row spacing could have optimized plant population by improving light interception, reducing inter-row competition, and enhancing root zone aeration. The seed capsule provided controlled nutrient release and improved early seedling vigour. Humic acid might have enhanced nutrient solubility, root elongation and seedling establishment. Neem powder could be effective in antifungal protection and pest deterrence at the early growth stages. While NPK biofertilizers perhaps stimulated microbial activity, promoting nutrient uptake and soil fertility. This integration led to better seedling establishment, increased biomass production and higher maize yield, making it an effective strategy for improving crop resilience and productivity. More research and advancement are required in the seed capsule technology to make it economically feasible for farmers. As majority of the research was carried out on maize, there may be doubts about how seed capsules will be helpful to improve the performance of other field crops. Further research is required to understand the efficacy of treatments under different environmental conditions which help to scale up the practical applicability for concrete real-world employment.

BIBLIOGRAPHY

Bibliography

Abbey, L., Abbey, J., Leke-Aladekoba, A., Iheshiulo, E. M. A., & Ijenyo, M. (2019). Biopesticides and biofertilizers: types, production, benefits, and utilization. Byproducts from Agriculture and Fisheries: *Adding Value for Food, Feed, Pharma, and Fuels,* 479-500.

Abd El-Naby, S. S., El-Ghandor, A. M. A., Abou El-Darag, I. H., & Mahmoud, M. A. (2024). Impact of Hydrogel Polymer on Water Productivity, Weed Control Efficiency and Yield of Broadcast-Seeded Rice. *International Journal of Plant & Soil Science*, 36(2), 9-27.

Abdo, A. I., El-Sobky, E. S. E., & Zhang, J. (2022). Optimizing maize yields using growth stimulants under the strategy of replacing chemicals with biological fertilizers. *Frontiers in Plant Science*, 13, 1069624.

Abobatta, W. (2018). Impact of hydrogel polymer in agricultural sector. *Advances in Agriculture and Environmental Science*, 1(2), 59-64.

Abrisham, E. S., Jafari, M., Tavili, A., Rabii, A., Zare Chahoki, M. A., Zare, S., Egan, T., Yazdanshenas, H., Ghasemian, D., & Tahmoures, M. (2018). Effects of a super absorbent polymer on soil properties and plant growth for use in land reclamation. Arid Land Research and Management, 32(4), 407-420.

Abubakar, A. I., Babuga, U. S., & Yohanna, H. (2019). Effect of Spacing on the Growth and Yield of Maize (Zea Mays L.) in Bauchi. Northern Guinea Savanna Zone of Nigeria. *International Journal of Agriculture and Food Sciences*, (ISSN: 2645-243X), 2, 001-013.

Acharya, P., Mir, S. A., & Nayak, B. (2017). Competence of biopesticide and neem in agriculture. *International Journal of Environment, Agriculture and Biotechnology*, 2(6), 238987.

Adhikari, N. P., Mishra, B. N., & Mishra, P. K. (2005). Effect of integrated nitrogen management on quality of aromatic rice. *Annals of Agricultural Research*, 26, 231-234.

Adusei, S., & Azupio, S. (2022). Neem: A novel biocide for pest and disease control of plants. *Journal of Chemistry*, 1, 6778554.

Agaba, H., Baguma Orikiriza, L. J., Osoto Esegu, J. F., Obua, J., Kabasa, J. D., & Hüttermann, A. (2010). Effects of hydrogel amendment to different soils on plant available water and survival of trees under drought conditions. *Clean–Soil, Air, Water*, 38(4), 328-335.

Agaba, H., Orikiriza, L. J., Obua, J., Kabasa, J. D., Worbes, M., & Hüttermann, A. (2011). Hydrogel amendment to sandy soil reduces irrigation frequency and improves the biomass of *Agrostis stolonifera*. *Agricultural Sciences*, 2(04), 544-550.

Ahemad, M., & Kibret, M. (2014). Mechanisms and applications of plant growth promoting rhizobacteria: current perspective. *Journal of King Saud University Science*, 26(1), 1-20.

Ahmed, E. M. (2015). Hydrogel: Preparation, characterization, and applications: A review. *Journal of Advanced Research*, 6(2), 105-121.

Ajeng, A. A., Abdullah, R., Malek, M. A., Chew, K. W., Ho, Y. C., Ling, T. C., Lau, B.F., & Show, P. L. (2020). The effects of biofertilizers on growth, soil fertility, and nutrients uptake of oil palm (*Elaeis guineensis*) under greenhouse conditions. *Processes,* 8(12), 1681.

Ajmal, A. W., Yasmin, H., Hassan, M. N., Khan, N., Jan, B. L., & Mumtaz, S. (2022). Heavy metal–resistant plant growth–promoting citrobacter werkmanii strain WWN1 and enterobacter cloacae strain JWM6 enhance wheat (*Triticum aestivum* L.) growth by modulating physiological attributes and some key antioxidants under multi-metal stress. *Frontiers in Microbiology*, 13, 815704.

Akanmu, A. O., Babalola, O. O., Venturi, V., Ayilara, M. S., Adeleke, B. S., Amoo, A. E., ... & Glick, B. R. (2021). Plant disease management: leveraging on the plant-microbe-soil interface in the biorational use of organic amendments. *Frontiers in Plant Science*, 12, 700507.

Akhter, J., Mahmood, K., Malik, K. A., Mardan, A., Ahmad, M., & Iqbal, M. M. (2004). Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea. *Plant Soil and Environment*, 50(10), 463-469.

Al-Amri, S. M. (2021). Application of bio-fertilizers for enhancing growth and yield of common bean plants grown under water stress conditions. *Saudi Journal of Biological Sciences*, 28(7), 3901-3908.

Albalasmeh, A. A., Mohawesh, O., Gharaibeh, M. A., Alghamdi, A. G., Alajlouni, M. A., & Alqudah, A. M. (2022). Effect of hydrogel on corn growth, water use efficiency, and soil properties in a semi-arid region. *Journal of the Saudi Society of Agricultural Sciences*, 21(8), 518-524.

Ali, A. M., Awad, M. Y., Hegab, S. A., Gawad, A. M. A. E., & Eissa, M. A. (2021). Effect of potassium solubilizing bacteria (*Bacillus cereus*) on growth and yield of potato. *Journal of Plant Nutrition*, 44(3), 411-420.

Ali, A. Y. A., Ibrahim, M. E. H., Zhou, G., Nimir, N. E. A., Jiao, X., Zhu, G., ... & Yue, W. (2020). Exogenous jasmonic acid and humic acid increased salinity tolerance of sorghum. Agronomy Journal, 112(2), 871-884.

Aliveni, A., Venkateswarlu, B., Rekha, M. S., Prasad, P. R. K., & Jayalalitha, K. (2020). Influence of crop geometry and nutrient management practices on productivity of finger millet: A review. *Journal of Pharmacognosy and Phytochemistry*, 9(4), 1143-1146.

Alori, E. T., Babalola, O. O., & Prigent-Combaret, C. (2019). Impacts of microbial inoculants on the growth and yield of maize plant. *The Open Agriculture Journal*, 13(1).

Amutha, R., Karunakaran, S., Dhanasekaran, S., Hemalatha, K., Monika, R., Shanmugapriya, P., & Sornalatha, T. (2014). Isolation and mass production of biofertilizer (Azotobacter and Phosphobacter). *International Journal of Latest Research in Science and Technology,* 3(1), 79-81.

Anli, M., Baslam, M., Tahiri, A., Raklami, A., Symanczik, S., Boutasknit, A., & Meddich, A. (2020). Biofertilizers as strategies to improve photosynthetic apparatus, growth, and drought stress tolerance in the date palm. *Frontiers in plant science*, 11, 516818.

Anonymous. (2016). Hydrogel in Agriculture. Retrieved from website: https://en.wikipedia.org/wiki/Hydrogel_agriculture

Anonymous. (2022). Agricultural Statistics at a Glance-2022. Ministry of Agriculture & Farmers Welfare, Department of Agriculture & Farmers Welfare, Economics and Statistics Division, Government of India. Retrieved from website: https://agricoop.nic.in/Documents/CWWGDATA/Agricultural_Statistics_at_a_Glance_2022_0.pdf

Anonymous. (2023). Second Advance Estimates of production of major crops released. Ministry of Agriculture & Farmers Welfare, Government of India. Retrieved from website: https://pib.gov.in/PressReleseDetail.aspx?PRID=1899193

Anupama & Parmar, B.S. (2012). Pusa hydrogel: An indigenous semi synthetic superabsorbent technology for conserving water and enhancing crop productivity. Indian Agricultural Research Institute (IARI).

Anupama, M. C., Kumar, R., Parmar, B. S., & Kumar, A. (2005). Performance of a new superabsorbent polymer on seedling and post planting growth and water use pattern of chrysanthemum grown under controlled environment. *Acta Horticulturae,* 618, 215-224.

APEDA. (2022). Agricultural and Processed Food Products Export Development Authority (APEDA), Ministry of Commerce and Industry, Government of India. Retrieved from website: https://apeda.gov.in/apedawebsite/SubHead_Products/Maize.htm

Arancon, N. Q., Edwards, C. A., Lee, S., & Byrne, R. (2006). Effects of humic acids from vermicomposts on plant growth. *European Journal of Soil Biology*, 42, S65-S69.

Arjumend, T., Abbasi, M. K., & Rafique, E. (2015). Effects of lignite-derived humic acid on some selected soil properties, growth and nutrient uptake of wheat (*Triticum aestivum* L.) grown under greenhouse conditions. *Pakistan Journal of Botany*, 47(6), 2231-2238.

Aslam, M. M., Waseem, M., Jakada, B. H., Okal, E. J., Lei, Z., Saqib, H. S. A., ... & Zhang, Q. (2022). Mechanisms of Abscisic Acid-Mediated Drought Stress Responses in Plants. *International Journal of Molecular Sciences*, 23(3).

Atarzadeh, S. H., Mojaddam, M., & Nejad, T. S. (2013). The interactive effects humic acid application and several of nitrogen fertilizer on remobilization star wheat. *International Journal of Biosciences*, 3(8), 116-123.

Azeem, M., Haider, M. Z., Javed, S., Saleem, M. H., & Alatawi, A. (2022). Drought stress amelioration in maize (*Zea mays* L.) by inoculation of Bacillus spp. strains under sterile soil conditions. *Agriculture,* 12(1), 50.

Azevedo, T.L.F., Bertonha, A., & Gonçalves, A.C.A. (2002). Uso de hidrogel na agricultura. Revista do programa ciências agroambientais. *Alta Floresta,* 1(1): 23-31.

Bai, W., Zhang, H., Liu, B., Wu, Y., & Song, J. (2010). Effects of super-absorbent polymers on the physical and chemical properties of soil following different wetting and drying cycles. *Soil Use and Management*, 26(3), 253-260.

Bairwa, D. D., Chaplot, P. C., Singh, D., Meena, R. H., Jat, M. L., & Meena, A. (2022). Effect of irrigation schedules based on IW-CPE ratio and hydrogel levels on nutrient uptake and total uptake of Isabgol (*Plantago ovata Forsk*.). *The Pharma Innovation Journal*, 11(1): 174-179.

Bakass, M., Mokhlisse, A., & Lallemant, M. (2002). Absorption and desorption of liquid water by a superabsorbent polymer: Effect of polymer in the drying of the soil and the quality of certain plants. *Journal of Applied Polymer Science*, 83(2), 234-243.

Bamagoos, A. A., Alharby, H. F., Belal, E. E., Khalaf, A. E., Abdelfattah, M. A., Rady, M. M., Ali, E.F. & Mersal, G. A. (2021). Phosphate-solubilizing bacteria as a panacea to alleviate stress effects of high soil CaCO3 content in Phaseolus vulgaris with special reference to P-releasing enzymes. *Sustainability*, 13(13), 7063.

Bargaz, A., Lyamlouli, K., Chtouki, M., Zeroual, Y., & Dhiba, D. (2018). Soil microbial resources for improving fertilizers efficiency in an integrated plant nutrient management system. *Frontiers in Microbiology*, 9, 1606.

Barihi, R., Panahpour, E., & Beni, M. H. M. (2013). Super absorbent polymer (hydrogel) and its application in agriculture. *World of Sciences Journal*, 1(15), 223-228.

Barin, M., Asadzadeh, F., Hosseini, M., Hammer, E. C., Vetukuri, R. R., & Vahedi, R. (2022). Optimization of biofertilizer formulation for phosphorus solubilizing by Pseudomonas fluorescens Ur21 via response surface methodology. *Processes*, 10(4), 650.

Basak, B. B., Maity, A., Ray, P., Biswas, D. R., & Roy, S. (2022). Potassium supply in agriculture through biological potassium fertilizer: A promising and sustainable option for developing countries. *Archives of Agronomy and Soil Science*, 68(1), 101-114.

Bechtaoui, N., Rabiu, M. K., Raklami, A., Oufdou, K., Hafidi, M., & Jemo, M. (2021). Phosphate-dependent regulation of growth and stresses management in plants. *Frontiers in Plant Science*, 12, 679916.

Beguería, S., Vicente-Serrano, S. M., & Angulo-Martínez, M. (2010). A multiscalar global drought dataset: the SPEIbase: a new gridded product for the analysis of drought variability and impacts. *Bulletin of the American Meteorological Society*, 91(10), 1351-1354.

Bera, B., Bokado, K., Barkha, & Arambam, S. (2024). Effect of humic acid on growth, yield and soil properties in rice: a review. *International Journal of Plant and Soil Science*, 36(6), 26–35.

Berek, A. K. (2014). Exploring the potential roles of biochars on land degradation mitigation. *Journal of Degraded and Mining Lands Management*, 1(3), 149.

Bernhard, B. J., & Below, F. E. (2020). Plant population and row spacing effects on corn: Plant growth, phenology, and grain yield. *Agronomy Journal*, 112(4), 2456-2465.

Bhatta, K., Chaulagain, L., Kafle, K., & Shrestha, J. (2019). Bio-efficacy of plant extracts against mustard Aphid (Lipaphis erysimi Kalt.) on rapeseed (*Brassica campestris* Linn.) under field and laboratory conditions. *Syrian Journal of Agricultural Research,* 6(4), 557-566.

Billingham, K. (2015). Humic products: potential or presumption for agriculture. NSW Agriculture? Can humic products improve my soil?

Bley, H., Gianello, C., Santos, L. D. S., & Selau, L. P. R. (2017). Nutrient release, plant nutrition, and potassium leaching from polymer-coated fertilizer. *Revista Brasileira de Ciência do Solo*, 41,1-11.

Bradáčová, K., Kandeler, E., Berger, N., Ludewig, U., & Neumann, G. (2020). Microbial consortia inoculants stimulate early growth of maize depending on nitrogen and phosphorus supply. *Plant, Soil and Environment*, 66(3), 105-112.

Bradford, M. M. (1976). A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Analytical biochemistry*, 72(1-2), 248-254.

Buwalda, S. J., Boere, K. W., Dijkstra, P. J., Feijen, J., Vermonden, T., & Hennink, W. E. (2014). Hydrogels in a historical perspective: From simple networks to smart materials. *Journal of controlled release*, 190, 254-273.

Bybordi, A., & Ebrahimian, E. (2013). Growth, yield and quality components of canola fertilized with urea and zeolite. *Communications in Soil Science and Plant Analysis,* 44(19), 2896-2915.

Canellas, L. P., Olivares, F. L., Canellas, N. O., Mazzei, P., & Piccolo, A. (2019). Humic acids increase the maize seedlings exudation yield. *Chemical and Biological Technologies in Agriculture*, 6, 1-14.

Chahal, R., Verma, S. K., & Singh, A. K. (2022). Effect of Biofertilizers on Nutrient Uptake by Green Gram [*Vigna radiata* (L.) Wilczek] under Agri-horti System in Vindhyan Region of Eastern Uttar Pradesh. *International Journal of Plant & Soil Science*, 34(23), 686-691.

Chaithra, G. M., & Sridhara, S. (2018). Yield and physiological parameters of maize as influenced by the application of super absorbent polymer and mulching under rainfed conditions. *International Journal of Current Microbiology and Applied Sciences*, 7(08), 216-24.

Channal, B.K. (2017). Effect of organic and inorganic sources of nutrients on soil fertilitand productivity of maize (*Zea mays* L.). (Doctor of science), University of Agriculture Science, Dharwad. Karnataka, India.

Chapman, H. D., & Pratt, P. F. (1962). Methods of analysis for soils, plants and waters. *Soil Science*, 93(1), 68.

Chaudhary, A., Chaudhary, P., Upadhyay, A., Kumar, A., & Singh, A. (2021). Effect of gypsum on plant growth promoting rhizobacteria. Environment and Ecology, 39, 1248–1256.

Chaudhary, A., Parveen, H., Chaudhary, P., Khatoon, H., & Bhatt, P. (2021). Rhizospheric microbes and their mechanism. *Microbial Technology for Sustainable Environment*, 79-93.

Chaudhary, P., Singh, S., Chaudhary, A., Sharma, A., & Kumar, G. (2022). Overview of biofertilizers in crop production and stress management for sustainable agriculture. *Frontiers in Plant Science*, 13, 930340.

Checchio, M. V., de Cássia Alves, R., de Oliveira, K. R., Moro, G. V., Santos, D. M. M. D., & Gratão, P. L. (2021). Enhancement of salt tolerance in corn using *Azospirillum brasilense*: an approach on antioxidant systems. *Journal of Plant Research*, 134, 1279-1289.

Chen, H., Koopal, L. K., Xiong, J., Avena, M., and Tan, W. (2017). Mechanisms of soil humic acid adsorption onto montmorillonite and kaolinite. *Journal of colloid and interface Science*. 504, 457–467.

Chen, Y., Yang, H., Shen, Z., & Ye, J. (2022). Whole-genome sequencing and potassium-solubilizing mechanism of *bacillus aryabhattai* SK1-7. *Frontiers in Microbiology*, 12, 722379.

Chevillard, A., Angellier-Coussy, H., Guillard, V., Gontard, N., & Gastaldi, E. (2012). Controlling pesticide release via structuring agropolymer and nanoclays based materials. *Journal of Hazardous Materials*, 205, 32-39.

Chhiba. I. M. (2008). Soil fertility related problems in Punjab. Chhiba. I. M., & Kukal. S. S. (Ed.). *Irrigation Water and Soil Fertility Management in Punjab*. Tech Bull II, Niche Area of Excellence, Department of Soils, Punjab Agricultural University, Ludhiana.

Chikarango, C., Sebastian, C., Tabarira J., & Tuarira, M. (2021). Hydrogel effect on growth and development of tomato seedlings. *International Journal of Plant Pathology and Microbiology*, 1(2), 48-52.

Chimate, P., Khobragade, N. H., Wahane, M. R., Rajemahadik, V. A., Thorat, S. B., Thakare, U. E., ... & Vardam, D. G. (2023). Effect of biofertilizers and NPK levels on yield and nutrient uptake by cluster bean (*Cyamopsis tetragonoloba* L. Taub.) in lateritic soils of Konkan. The Pharma Innovation Journal, 12(1), 2396-2398.

Cholavardan, D., & VVS, J. K. (2023). Assessing the Effect of Irrigation Levels and Hydrogel on Growth and Yield of Wheat (*Triticum aestivum* L.). *International Journal of Environment and Climate Change*, 13(10), 2644-2649.

Cookson, P., Abdel Rehman, H., & Hirsbrunner, P, (2001), Effect of hydrophobic polymer application and irrigation rates on yield of field grown okra. *Agricultural Sciences* 6(1-2): 67-75.

DACNET. (2023). Department of Agriculture and Cooperation Network. Retrieved from website: https://eands.dacnet.nic.in/

Dal, C., C., Ferrari, M., Visioli, G., Lauro, M., Fornasier, F., Barion, G., ... & Vamerali, T. (2020). Effects of seed-applied biofertilizers on rhizosphere biodiversity and growth of common wheat (*Triticum aestivum* L.) in the field. *Frontiers in Plant Science*, 11, 513542.

Daniel, A. I., Fadaka, A. O., Gokul, A., Bakare, O. O., Aina, O., Fisher, S., Burt, A. F., Mavumengwana, V., Keyster, M., & Klein, A. (2022). Biofertilizer: the future of food security and food safety. Microorganisms, 10(6), 1220.

Dar, G. H., Kamili, A. N., Chishti, M. Z., Dar, S. A., Tantry, T. A., & Ahmad, F. (2016). Characterization of Aeromonas sobria isolated from fish Rohu (*Labeo rohita*) collected from polluted pond. *Journal of Bacteriology and Parasitology*, 7(3), 1-5.

Dar, S. A., & Bhat, R. A. (2020). Aquatic pollution stress and role of biofilms as environment cleanup technology. Fresh water pollution dynamics and remediation, 293-318.

Dar, S. B., & Ram, H. (2017). Productivity of wheat (*Triticum aestivum* L.) in relation to hydrogel as influenced by different irrigation regimes and nutrient levels. *International Journal of Chemical Studies*, 5(5), 609-613.

Das, S. K., & Avasthe, R. (2020). Packages of organic nutrient management as soil policy for upgrading cropping system to restore soil productivity. *Organic agriculture*, 33.

Das, S. K., Avasthe, R. K., Matber, S., & Roy, A. (2018). Managing soil fertility under organic production system through integrated approach. *Green farming*, 9(3), 449-454.

Daur, I., & Bakhashwain, A. A. (2013). Effect of humic acid on growth and quality of maize fodder production. *Pakistan Journal of Botany*, 45(S1), 21-25.

de Castro, T. A. V. T., Berbara, R. L. L., Tavares, O. C. H., da Graca Mello, D. F., Pereira, E. G., de Souza, C. D. C. B., ... & García, A. C. (2021). Humic acids induce a eustress state via photosynthesis and nitrogen metabolism leading to a root growth improvement in rice plants. *Plant Physiology and Biochemistry*, 162, 171-184.

de Kruif, C. K., Anema, S. G., Zhu, C., Havea, P., & Coker, C. (2015). Water holding capacity and swelling of casein hydrogels. *Food Hydrocolloids*, 44, 372-379.

de Melo, B. A. G., Motta, F. L., & Santana, M. H. A. (2016). Humic acids: Structural properties and multiple functionalities for novel technological developments. *Materials Science and Engineering*: C, 62, 967-974.

Dehkordi, D. K. (2016). The effects of Superabsorbent polymers on soils and plants. *Pertanika Journal of Tropical Agricultural Science*, 39(3), 267-298.

Dervash, M. A., Bhat, R. A., Shafiq, S., Singh, D. V., & Mushtaq, N. (2020). Biotechnological intervention as an aquatic clean up tool. Fresh water pollution dynamics and remediation, 183-196.

Deshmukh, S. B., Karanjikar, P. N., Patil, P. D., Sabne, K. S., & Mamdi, S. J. (2023). Effect of humic acid and fertilizer on growth and yield of maize (*Zea mays* L.). *The Pharma Innovation Journal*, 12(11), 1996-1998.

Dewi, T. K., Antonius, S., Sutisna, E., & Mulyani, N. (2021, May). The responses of soil enzyme and microbial activities of shallot plantation under treatments of Liquid Organic Biofertilizer and sprout extract and its effect on the yield. In *IOP Conference Series: Earth and Environmental Science* (Vol. 762, No. 1, p. 012050). IOP Publishing.

Dhakal, Y., Meena, R. S., & Kumar, S. (2016). Effect of INM on nodulation, yield, quality and available nutrient status in soil after harvest of greengram. *Legume Research-An International Journal*, 39(4), 590-594.

Dietz, K. J., & Pfannschmidt, T. (2011). Novel regulators in photosynthetic redox control of plant metabolism and gene expression. *Plant Physiology*, 155(4), 1477-1485.

Dinesh, R., Srinivasan, V., Hamza, S., & Manjusha, A. (2010). Short-term incorporation of organic manures and biofertilizers influences biochemical and microbial characteristics of soils under an annual crop [Turmeric (*Curcuma longa* L.)]. Bioresource technology, 101(12), 4697-4702.

Divekar, P. A., Narayana, S., Divekar, B. A., Kumar, R., Gadratagi, B. G., Ray, A., ... & Behera, T. K. (2022). Plant secondary metabolites as defense tools against herbivores for sustainable crop protection. *International Journal of Molecular Sciences*, 23(5), 2690.

Djajadi, R., Syaputra., & Hidayati, S.N. (2019). Effect of NPK fertilizer, biofertilizer containing N fixer and P solubilizer, and green manure of *C. juncea* on nutrients uptake and growth of sugarcane. *IOP Conf. Series: Earth and Environmental Science* 418, 012068.

Dong, X., Lv, L., Wang, W., Liu, Y., Yin, C., Xu, Q., ... & Liu, X. (2019). Differences in distribution of potassium-solubilizing bacteria in forest and plantation soils in Myanmar. *International Journal of Environmental Research and Public Health*, 16(5), 700.

Dos Santos, T. B., Ribas, A. F., de Souza, S. G. H., Budzinski, I. G. F., & Domingues, D. S. (2022). Physiological responses to drought, salinity, and heat stress in plants: a review. *Stresses*, 2(1), 113-135.

Duan, C., Mei, Y., Wang, Q., Wang, Y., Li, Q., Hong, M., & Fang, L. (2022). Rhizobium inoculation enhances the resistance of alfalfa and microbial characteristics in copper-contaminated soil. *Frontiers in Microbiology*, 12, 781831.

Duary, S. (2020). Humic Acid-A critical review. *International Journal of Current Microbiology and Applied Sciences*, 9(10), 2236-2241.

Economics and Statistics. (2023). Directorate of Economics and Statistics (DES), Department of Agriculture, Cooperation and Farmers Welfare (DAC & FW), Government of India. Retrieved from website: https://desagri.gov.in/#

Eissa, M. A., & Negim, O. E. (2019). Nutrients uptake and water use efficiency of drip irrigated maize under deficit irrigation. *Journal of Plant Nutrition*, 42(1), 79-88.

Ekebafe, L. O., Ogbeifun, D. E., & Okieimen, F. E. (2011). Polymer applications in agriculture. *Biokemistri,* 23(2): 81-89.

Ekin, Z. (2019). Integrated use of humic acid and plant growth promoting rhizobacteria to ensure higher potato productivity in sustainable agriculture. *Sustainability*, 11(12), 3417.

El-Asmar, J., Jaafar, H., Bashour, I., Farran, M. T., & Saoud, I. P. (2017). Hydrogel banding improves plant growth, survival, and water use efficiency in two calcareous soils. *CLEAN – Soil, Air, Water*, *45*(7), 1700251.

El-Hady, O. A., & Abo-Sedera, S. A. (2006). Conditioning effect of composts and acrylamide hydrogels on a sandy calcareous soil. II-Physico-bio-chemical properties of the soil. *International Journal of Agriculture & Biology*, 8(6): 876-884.

Eliaspour, S., Seyed Sharifi, R., Shirkhani, A., & Farzaneh, S. (2020). Effects of biofertilizers and iron nano-oxide on maize yield and physiological properties under optimal irrigation and drought stress conditions. *Food Science & Nutrition*, 8(11), 5985-5998.

Etesami, H., & Maheshwari, D. K. (2018). Use of plant growth promoting rhizobacteria (PGPRs) with multiple plant growth promoting traits in stress agriculture: Action mechanisms and future prospects. *Ecotoxicology and Environmental Safety*, 156, 225-246.

Etesami, H., Mirseyed Hosseini, H., & Alikhani, H. A. (2014). Bacterial biosynthesis of 1-aminocyclopropane-1-caboxylate (ACC) deaminase, a useful trait to elongation and endophytic colonization of the roots of rice under constant flooded conditions. Physiology and Molecular Biology of Plants, 20, 425-434.

Fahsi, N., Mahdi, I., Mesfioui, A., Biskri, L., & Allaoui, A. (2021). Plant Growth-Promoting Rhizobacteria isolated from the Jujube (*Ziziphus lotus*) plant enhance wheat growth, Zn uptake, and heavy metal tolerance. *Agriculture*, 11(4), 316.

Fan, H. M., Wang, X. W., Sun, X., Li, Y. Y., Sun, X. Z., & Zheng, C. S. (2014). Effects of humic acid derived from sediments on growth, photosynthesis and chloroplast ultrastructure in chrysanthemum. *Scientia Horticulturae*, 177, 118-123.

Fang, L., Ju, W., Yang, C., Jin, X., Liu, D., Li, M., & Zhang, C. (2020). Exogenous application of signaling molecules to enhance the resistance of legume-rhizobium symbiosis in Pb/Cd-contaminated soils. *Environmental Pollution*, 265, 114744.

FAO, IFAD, UNICEF, WFP and WHO. (2022). The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable. Rome, FAO.

FAO. (2021). Agriculture on proving grounds- Damage and losses. Retrieved from website: https://www.fao.org/resources/digital-reports/disasters-in-agriculture/en/

FAO. (2023). Food and Agriculture Organization of the United Nations. Retrieved from website: https://www.fao.org/faostat/en/#data/RFN

FAOSTAT. (2019). Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). Retrieved from website: https://www.fao.org/faostat/en/#data/QCL

FAOSTAT. (2021). Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). Retrieved from website: http://www.fao.org/statistics/en

Farooq, M., Aziz, T., Basra, S. M. A., Cheema, M. A., & Rehman, H. (2008). Chilling tolerance in hybrid maize induced by seed priming with salicylic acid. *Journal of Agronomy and Crop Science*, 194(2), 161-168.

Fasusi, O. A., Cruz, C., & Babalola, O. O. (2021). Agricultural sustainability: microbial biofertilizers in rhizosphere management. Agriculture, 11(2), 163.

Fitriatin, B. N., Yusuf, M. I. M., Sofyan, E. T., & Nurbaity, A. (2021). Biofertilizers application to improve growth of maize and soil nutrients. In *E3S Web of Conferences. EDP Sciences*. 316, 03020.

Fortt, J., González, M., Morales, P., Araya, N., Remonsellez, F., Coba de la Peña, T., ... & Stoll, A. (2022). Bacterial modulation of the plant ethylene signaling pathway improves tolerance to salt stress in lettuce (*Lactuca sativa* L.). *Frontiers in Sustainable Food Systems,* 6, 768250.

Friedlander, B. (2021). Climate change has hurt farm productivity. Cornell Chronicle. Retrieved from website: https://earth.stanford.edu/news/climate-change-has-hurt-farm-productivity

Ghany, T. M. A., Alawlaqi, M. M., & Al-Abboud, M. A. (2013). Role of biofertilizers in agriculture: a brief review. *Mycopath*, 11(2), 95-101.

Ghosh, A., Dutta, T., Saha, A. K., Kar B. N.S., Mandal K., & Bajpai A. K. (2009), planting geometry can affect leaf yield and quality in a mulberry chawki garden. *Journal of Crop and Weed*, 5(1):44-47.

Gilbert, C., Peter, S., Ng'etich Wilson, M. E., Francis, M., & Sylvester, K. (2014). Effects of Hydrogels on Soil Moisture and Growth of Leucaena Pallida in Semi Arid Zone of Kongelai, West Pokot County. *Open Journal of Atmospheric and Climate Change*. 1(2):2374-3794.

Glick, B. R. (2012). Plant growth-promoting bacteria: mechanisms and applications. *Scientifica*, (1), 963401.

Gohil, N. B., Ramani, V. P., Kadivala, V. H., & Kacha, R. P. (2021). Effects of bio-NPK consortium on growth, yield and nutrient uptake by rice under clay loam textured soil. *Journal of the Indian Society of Soil Science*, 69(2), 179-186.

Gohil, R. B., Raval, V. H., Panchal, R. R., & Rajput, K. N. (2022). Plant growth-promoting activity of Bacillus sp. PG-8 isolated from fermented panchagavya and its effect on the growth of Arachis hypogea. *Frontiers in Agronomy*, 4, 805454.

Gollenbeek, L., & van der Weide, R. (2020). Prospects for humic acid products from digestate in the Netherlands: quickscan (No. WPR-867). Stichting Wageningen Research, Wageningen Plant Research, Business unit Open Teelten. 5-40.

Gosain, A. K., Rao, S., & Basuray, D. (2006). Climate change impact assessment on hydrology of Indian river basins. *Current science*, 90(3), 346-353.

Gou, J. Y., Suo, S. Z., Shao, K. Z., Zhao, Q., Yao, D., Li, H. P., ... & Rensing, C. (2020). Biofertilizers with beneficial rhizobacteria improved plant growth and yield in chili

(*Capsicum annuum* L.). *World Journal of Microbiology and Biotechnology*, 36, 1-12.

Grabiński, J., & Wyzińska, M. (2018). The effect of superabsorbent polymer application on yielding of winter wheat (*Triticum aestivum* L.). *Research for Rural Development*, 2, 55-61.

Gümüş, İ., & Şeker, C. (2015). Influence of humic acid applications on soil physicochemical properties. *Solid Earth*, 7, 2481-2500.

Guo, J., Shi, W., Wen, L., Shi, X., & Li, J. (2020). Effects of a super-absorbent polymer derived from poly-γ-glutamic acid on water infiltration, field water capacity, soil evaporation, and soil water-stable aggregates. *Archives of Agronomy and Soil Science*, 66(12), 1627-1638.

Gupta, G., Panwar, J., Akhtar, M. S., & Jha, P. N. (2012). Endophytic nitrogen-fixing bacteria as biofertilizer. *Sustainable Agriculture Reviews*: 11, 183-221.

Hafiz-Afham, K., Hasan, N. A., Rafii, M. Y., & Sidik, N. J. (2023, March). The growth impact of Capsicum annuum crops in hydrogel incorporated media. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1155, No. 1, p. 012031). IOP Publishing.

Harman, G., Khadka, R., Doni, F., & Uphoff, N. (2021). Benefits to plant health and productivity from enhancing plant microbial symbionts. Frontiers in Plant Science, 11, 610065.

Hasler, K., Olfs, H. W., Omta, O., & Bröring, S. (2017). Drivers for the adoption of different eco-innovation types in the fertilizer sector: A review. Sustainability, 9(12), 2216.

Heidari, H., & Hosseini, A. (2024). Hydrogel polymer improves plant biomass and leaf relative water content in dill and fenugreek. *Field & Vegetable Crops Research/Ratarstvo i povrtarstvo*, *61*(2).

Hayes, M. H., & Swift, R. S. (2020). Vindication of humic substances as a key component of organic matter in soil and water. *Advances in Agronomy*, 163, 1-37.

He, M., He, C. Q., & Ding, N. Z. (2018). Abiotic stresses: general defenses of land plants and chances for engineering multistress tolerance. *Frontiers in Plant Science*, 9, 1771.

Hennessy, L. M., Popay, A. J., Glare, T. R., Finch, S. C., Cave, V. M., & Rostás, M. (2022). Olfactory responses of Argentine stem weevil to herbivory and endophyte-colonisation in perennial ryegrass. *Journal of Pest Science*, 95(1), 263-277.

Hossain, M. A., & Nagooru, M. R. (2011). Biochemical profiling and total flavonoids contents of leaves crude extract of endemic medicinal plant Corydyline terminalis L. Kunth. *Pharmacognosy Journal*, 3(24), 25-30.

Hummadi, E. H., Cetin, Y., Demirbek, M., Kardar, N. M., Khan, S., Coates, C. J., ... & Butt, T. M. (2022). Antimicrobial volatiles of the insect pathogen *Metarhizium brunneum*. *Journal of Fungi*, 8(4), 326.

Hussain, S., Khaliq, A., Ali, B., Hussain, H. A., Qadir, T., & Hussain, S. (2019). Temperature extremes: Impact on rice growth and development. Plant Abiotic Stress Tolerance: Agronomic, *Molecular and Biotechnological Approaches*, 153-171.

Hussain, T., Khan, I. A., Malik, M. A., & Ali, Z. (2006). Breeding potential for high temperature tolerance in corn (*Zea mays* L.). *Pakistan Journal of Botany*, 38(4), 1185.

Huettermann, A., Orikiriza, L. J., & Agaba, H. (2009). Application of superabsorbent polymers for improving the ecological chemistry of degraded or polluted lands. *CLEAN–Soil, Air, Water*, *37*(7), 517-526.

Ibrahim, I. A., Yehia, W. M., Saleh, F. H., Lamlom, S. F., Ghareeb, R. Y., El-Banna, A. A., & Abdelsalam, N. R. (2022). Impact of plant spacing and nitrogen rates on growth characteristics and yield attributes of Egyptian cotton (*Gossypium barbadense* l.). *Frontiers in Plant Science*, 13, 916734.

ICAR. (2024). A novel method of storing and PGPR/Microbes through Biocapsules. Retrieved from website: https://icar.org.in/node/11931#:~:text=The%20ICAR%2DIndian%20Institute%20of,13%2D08%2D2013

Indian Council of Agricultural Research (ICAR)- Indian Institute of Maize Research (IIMR) (2020). Retrieved from website:https://iimr.icar.gov.in/?page_id=51#:~:text=In%20India%2C%20maize%20is%20principally,many%20biotic%20and%20abiotic%20stresses.

Igiehon, N. O., Babalola, O. O., & Aremu, B. R. (2019). Genomic insights into plant growth promoting rhizobia capable of enhancing soybean germination under drought stress. *BMC Microbiology*, 19, 1-22.

International Pepper Community. (2024). Biocapsules. Retrieved from website: https://www.ipcnet.org/research/biocapsules/

International Union of Pure and Applied Chemistry. (2004). Definitions of terms relating to reactions of polymers and to functional polymeric materials (lUPAC Recommendations 2003). *Pure Applied Chemistry*. 76(4): 889-906.

IPCC (Intergovernmental Panel on Climate Change). (2007). Summary for policymakers. In: Climate Change 2007: The physical science basis (Ed. by Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor M. &Miller H. L.). Cambridge University Press, UK.

IPCC (Intergovernmental Panel on Climate Change). (2022). Synthesis report of the sixth assessment report. In: Climate change (Ed.) Portner, H.O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A. and Rama, B. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp: 3056.

Islam, M. R., Hu, Y., Mao, S., Jia, P., Eneji, A. E., & Xue, X. (2011). Effects of water-saving superabsorbent polymer on antioxidant enzyme activities and lipid peroxidation in corn (*Zea mays* L.) under drought stress. *Journal of the Science of Food and Agriculture*, 91(5), 813-819.

Ismail, H., Irani, M., & Ahmad, Z. (2013). Starch-based hydrogels: present status and applications. *International Journal of Polymeric Materials and Polymeric Biomaterials*, 62(7), 411-420.

Jackson, M. (1958). Soil chemical analysis prentice Hall. Inc., Englewood Cliffs, NJ, 498(1958), 183-204.

Jackson, M.L. (1973). Soil chemical analysis. Prentice Hall of India Private Limited, New Delhi, p. 498.

Jagadish. (2020). Neem cake fertilizer, uses, applications and benefits, Agri farming. Retrieved from website: https://www.agrifarming.in/neem-cake-fertilizer-uses-application-benefits

Jahan, A. M. M., Bachchu, M. A. A., Rahman, M. H., Ara, R., & Al Helal, M. M. (2019). Bioactivities of four botanical extracts against rice. *Journal of Science and Technology,* 32, 44.

Jain, D., Sharma, J., Kaur, G., Bhojiya, A. A., Chauhan, S., Sharma, V., Suman, A., Mohan, S.R., & Maharjan, E. (2021). Phenetic and molecular diversity of nitrogen fixating plant growth promoting *Azotobacter* isolated from semiarid regions of India. BioMed Research International, 2021, 6686283.

Jamwal, S., Dawson, J., & Kashyap, C. (2023). Effect of Phosphorus and Hydrogel on Growth and Yield of Maize (*Zea mays* L.). *International Journal of Environment and Climate Change,* 13(9), 2122-2128.

Jat, S. L., Shivay, Y. S., & Parihar, C. M. (2011). Dual purpose summer legumes and zinc fertilization for improving productivity and zinc utilization in aromatic hybrid rice (*Oryza sativa* L.). *Indian Journal of Agronomy*, 56(4), 328-333.

Jeevan, R. J., Ananthakumar, M. A., Kadalli, G. G., Thimmegowda, M. N., & Asha, N. N. (2023). Influence of hydrogel on growth, yield and soil properties at varied moisture regimes under drip fertigation of tomato (*Solanum lycopersicum* L.). *The Pharma Innovation Journal*, 12(2), 1483-1486.

Jha, A. K., Pandey, S., & Shukla, R. S. (2020). Effect of Seed Rate and Dibbling on Growth, Yield Attributes and Yield of Different Varieties of Wheat (*Triticum aestivum*) in Madhya Pradesh, India. *International Journal of Current Microbiology and Applied Sciences*. 9(6): 707-711.

Jimenez-Jimenez, S., Santana, O., Lara-Rojas, F., Arthikala, M. K., Armada, E., Hashimoto, K., ... & Cárdenas, L. (2019). Differential tetraspanin genes expression and subcellular localization during mutualistic interactions in *Phaseolus vulgaris*. *PLoS One,* 14(8), e0219765.

Jing, X., Cui, Q., Li, X., Yin, J., Ravichandran, V., Pan, D., ... & Zhang, Y. (2020). Engineering Pseudomonas protegens Pf-5 to improve its antifungal activity and nitrogen fixation. *Microbial Biotechnology*, 13(1), 118-133.

Jong, S. J., KarunaKaran, K., Wasli, M. E., Musa, Z., & Chin, S. F. (2024). Cellulose-Based Hydrogel as a Natural Medium for Paddy Seed Germination. *Starch-Stärke*, 76(1-2), 2200234.

Kalhapure, A., Kumar, R., Singh, V. P., & Pandey, D. S. (2016). Hydrogels: A boon for increasing agricultural productivity in water-stressed environment. *Current science*, **111**(11), 1773–1779.

Kalita, N., Bhuyan, S., Maibangsa, S., & Saud, R. K. (2019). Effect of Biofertilizer seed treatment on Growth, yield and economics of toria (*Brassica campestris* L.) under rainfed condition in hill zone of Assam. *Current Agriculture Research Journal*, 7(3), 332.

Kant, S., Kumar, A., Kumar, S., Kumar, V., & Gurjar, O. P. (2017). Effect of biofertilizers and P-levels on yield, nutrient content, uptake and physico-chemical properties of soil under blackgram (*Vigna mungo* L*.). International journal of current microbiology and applied sciences*, 6(3), 1243-1251.

Kasahara, H. (2016). Current aspects of auxin biosynthesis in plants. Bioscience, biotechnology, and biochemistry, 80(1), 34-42.

Kawalekar, J. S. (2013). Role of biofertilizers and biopesticides for sustainable agriculture. *Journal of Bio Innovation*, 2(3), 73-78.

Khaled, H., & Fawy, H. A. (2011). Effect of different levels of humic acids on the nutrient content, plant growth, and soil properties under conditions of salinity. *Soil and Water Research*, 6(1), 21.

Khan, E. A., Aslam, M., Ahmad, H. K., Ayaz, M., & Hussain, A. (2010). Effect of row spacing and seeding rates on growth yield and yield components of chickpea. *Sarhad Journal of Agriculture*, 26(2), 201-211.

Khan, R. U., Rashid, A., Khan, M. S., & Ozturk, E. (2010). Impact of humic acid and chemical fertilizer application on growth and grain yield of rainfed wheat (*Triticum aestivum* L.). *Pakistan Journal of Agricultural Research*, 23(3-4).

Khan, S. A., Khan, S. U., Qayyum, A., Gurmani, A. R., Khan, A., Khan, S. M., ... & Amin, B. A. Z. (2019). Integration of humic acid with nitrogen wields an auxiliary impact on physiological traits, growth and yield of maize (*Zea mays* L.) varieties. *Applied Ecology & Environmental Research*, 17(3), 6783-6799.

Köhl, J., Kolnaar, R., & Ravensberg, W. J. (2019). Mode of action of microbial biological control agents against plant diseases: relevance beyond efficacy. *Frontiers in Plant Science,* 10, 454982.

Kong, W., Li, Q., Li, X., Su, Y., Yue, Q., & Gao, B. (2019). A biodegradable biomass-based polymeric composite for slow release and water retention. *Journal of Environmental Management*, 230, 190-198.

Kopittke, P. M., Menzies, N. W., Wang, P., McKenna, B. A., & Lombi, E. (2019). Soil and the intensification of agriculture for global food security. *Environment International,* 132, 105078.

Koupai, J. A., Eslamian, S. S., & Kazemi, J. A. (2008). Enhancing the available water content in unsaturated soil zone using hydrogel, to improve plant growth indices. *Ecohydrology & Hydrobiology*, 8(1), 67-75.

Kreye, C., Bouman, B. A. M., Castaneda, A. R., Lampayan, R. M., Faronilo, J. E., Lactaoen, A. T., & Fernandez, L. (2009). Possible causes of yield failure in tropical aerobic rice. *Field Crops Research*, 111(3), 197-206.

Kumar Naik, A. H., Chaithra, G. M., Kiran Kumar, N., Madhu, G., Nataraja, M., Umesha, S., & Madhu, B. M. (2020). Effect of hydrogel on growth, yield and economics of rainfed castor. *The Pharma Innovation Journal*, 9(7), 36-39.

Kumar, H., Dawson, J., & Sanodiya, L.K. (2022). Influence of bio-fertilizer and organic manures on growth and yield of baby corn (*Zea mays* L.) in Prayagraj condition. *The Pharma Innovation,* 11(8), 891-895.

Kumar, M. S., Reddy, G. C., Phogat, M., & Korav, S. (2018). Role of bio-fertilizers towards sustainable agricultural development: A review. *Journal of Pharmacognosy and Phytochemistry,* 7(6), 1915-1921.

Kumar, R., Nadukeri, S., Kolakar, S. S., Hanumanthappa, M., Shivaprasad, M., & Dhananjaya, B. N. (2018). Effect of hydrogel on growth, fresh yield and essential oil content of ginger (*Zingiber officinale* Rosc.). *Journal of Pharmacognosy and Phytochemistry*, 7(3S), 482-485.

Kumar, S. S. H., & Shankaralingappa, B. C. (2017). Effect of crop geometry in maize based intercropping system. Mysore *Journal of Agricultural Sciences,* 51(2), 425-439.

Kumar, S., Sharma, P. K., Yadav, M. R., Sexena, R., Gupta, K. C., Kumar, R., Garg, N.K., & Yadav, H. L. (2019). Effect of irrigation levels and moisture conserving polymers on growth, productivity and profitability of wheat. *Indian Journal of Agricultural Sciences*, 89(3), 509-514.

Kumar, S., Sindhu, S. S., & Kumar, R. (2022). Biofertilizers: An ecofriendly technology for nutrient recycling and environmental sustainability. *Current Research in Microbial Sciences*, 3, 100094.

Kumar, V. S., & Navaratnam, V. (2013). Neem (Azadirachta indica): Prehistory to contemporary medicinal uses to humankind. *Asian Pacific Journal of Tropical Biomedicine*, 3(7), 505-514.

Kumudha, P. (2005). Studies on the effect of biofertilizers on the germination of *Acacia nilotica* Linn. seeds. *Advances in Plant Sciences*, 18(11), 679-84.

Kumudha, P., & Gomathinayagam, M. (2007). Studies on the effect of biofertilizers on germination of *Albizia lebbek* (L) Benth. seeds. *Advances in Plant Sciences*, 20(11), 417-21.

Lahlali, R., Ezrari, S., Radouane, N., Kenfaoui, J., Esmaeel, Q., El Hamss, H., ... & Barka, E. A. (2022). Biological control of plant pathogens: A global perspective. *Microorganisms*, 10(3), 596.

Lal, M., Kaur, M., Singh, S., & Chaudhary, T. (2022). Response of crop geometry and phosphorus levels on field pea (*Pisum sativum* L.) varieties. *Journal of Soils and Crops,* 32(2), 240-245.

Langaroodi, N. B. S., Ashouri, M., Dorodian, H. R., & Azarpour, E. (2013). Study effects of super absorbent application, saline water and irrigation management on yield and yield components of peanut (*Arachis hypogaea* L.). *Annals of Biological Research* 4(1), 160-169.

Laskosky, J. D., Mante, A. A., Zvomuya, F., Amarakoon, I., & Leskiw, L. (2020). A bioassay of long-term stockpiled salvaged soil amended with biochar, peat, and humalite. *Agrosystems, Geosciences & Environment*, 3(1), e20068.

Laxmi, S., Chanu, P. H., Rani, P., Rai, S., Prasad, S. K., & Singh, R. K. (2019). Effect of hydrogel on soil moisture stress. *Journal of Pharmacognosy and Phytochemistry*, 8(5S), 316-320.

Lee, L. H., Wu, T. Y., Shak, K. P. Y., Lim, S. L., Ng, K. Y., Nguyen, M. N., & Teoh, W. H. (2018). Sustainable approach to biotransform industrial sludge into organic fertilizer via vermicomposting: A mini-review. *Journal of Chemical Technology & Biotechnology*, 93(4), 925-935.

Lenka, S., Lenka, N. K., Singh, A. B., Singh, B., & Raghuwanshi, J. (2017). Global warming potential and greenhouse gas emission under different soil nutrient management practices in soybean–wheat system of central India. *Environmental Science and Pollution Research*, 24, 4603-4612.

Li, N., Euring, D., Cha, J. Y., Lin, Z., Lu, M., Huang, L. J., & Kim, W. Y. (2021). Plant hormone-mediated regulation of heat tolerance in response to global climate change. *Frontiers in Plant Science*, 11, 627969.

Liao, R., Wu, W., Ren, S. & Yang, P. (2016). Effects of superabsorbent polymers on the hydraulic parameters and water retention properties of soil. *Journal of Nanomaterials,* 5403976.

Linares, C., Díaz, J., Negev, M., Martínez, G. S., Debono, R., & Paz, S. (2020). Impacts of climate change on the public health of the Mediterranean Basin population-current situation, projections, preparedness and adaptation. *Environmental Research*, 182, 109107.

Liu, Q., Hallerman, E., Peng, Y., & Li, Y. (2016). Development of Bt rice and Bt maize in China and their efficacy in target pest control. *International Journal of Molecular Sciences*, 17(10), 1561.

Liu, S., Gu, Y., Wang, X., Li, X., & Wang, Y. (2020). Husk Leaf Senescence Characteristics of Spring Maize (*Zea mays* L.) Cultivated in Two Row Directions and Three Plant Spacings in Northeast China. *Agronomy*, 10(8), 1216.

Lokanadhan, S., Muthukrishnan, P., & Jeyaraman, S. (2012). Neem products and their agricultural applications. *Journal of Biopesticides*, 5, 72.

Maftu'ah, E., Susilawati, A., Lestari, Y., Karolinoerita, V., Mukhlis, M., & Sulaeman, Y. (2023). Application of bio and NPK fertilizer to improve yield soybean and acid sulfate soil properties in Indonesia. *Chilean Journal of Agricultural Research*, 83(1), 52-62.

Mahanty, T., Bhattacharjee, S., Goswami, M., Bhattacharyya, P., Das, B., Ghosh, A.& Tribedi. P. (2016). Biofertilizers: a potential approach for sustainable agriculture development. Environmental Science 23:1–21.

Mahla, S. K., & Wanjari, S. S. (2017). Response of wheat to irrigation and hydrogel with nutrient management. *International Journal of Agricultural Science and Research*, 7(2), 267-272.

Mahmoodi-Babolan, N., Nematollahzadeh, A., Heydari, A., & Merikhy, A. (2019). Bioinspired catecholamine/starch composites as superadsorbent for the environmental remediation. *International Journal of Biological Macromolecules*, 125, 690-699.

Mahmud, A. A., Yahaya, S. M., Dhaked, G. S., Jain, D., & Bhojiya, A. A. (2022). Impacts of NPK consortia biofertilizer and mineral fertilizer on growth and yield of two maize (Zea mays L.) hybrids in Rajasthan-India. *Diyala Agricultural Sciences Journal*, 14(2), 100-117.

Maize Outlook. (2021). Maize Outlook Report-January to May 2021, Agricultural Market Intelligence Centre. Acharya N. G. Ranga Agricultural University (ANGRAU), Lam, Guntur. Retrieved from website: https://angrau.ac.in/downloads/AMIC/OutlookReports/2021/7-MAIZE_January%20to%20December%202021.pdf

Maize Outlook. (2024). Andhra Pradesh Agricultural and Horticultural Research Authority. Acharya N. G. Ranga Agricultural University, Lam, Guntur. Andhra Pradesh. Retrieved from website: https://www.pjtsau.edu.in/files/AgriMkt/2024/March/Maize-March-2024.pdf

Maji, D., Misra, P., Singh, S., & Kalra, A. (2017). Humic acid rich vermicompost promotes plant growth by improving microbial community structure of soil as well as root nodulation and mycorrhizal colonization in the roots of Pisum sativum. *Applied Soil Ecology*, 110, 97-108.

Malaa, P.H., Banuprakasha, K.G., Vinodaa, K. S., Sadatullaa, F. G. G., & Hanumanthappa, C. (2023). Efficacy of hydrogels under sensor based irrigation on soil nutrient status of tree mulberry. *International Journal of Plant & Soil Science*. 35(23), 617-625.

Malla, G., Bhatia, A., Pathak, H., Prasad, S., Jain, N., & Singh, J. (2005). Mitigating nitrous oxide and methane emissions from soil in rice–wheat system of the Indo-Gangetic plain with nitrification and urease inhibitors. *Chemosphere*, *58*(2), 141-147.

Malusa, E., & Vassilev, N. (2014). A contribution to set a legal framework for biofertilisers. *Applied Microbiology and Biotechnology*, 98, 6599-6607.

Mamathashree, C. M., Girijesh, G. K., Dinesh Kumar, M., & Mavarkar, N. S. (2019). Performance of baby corn under paired row of pigeon pea+ baby corn intercropping system. *International Journal of Current Microbiology and Applied Sciences*, 8(04), 211-221.

Manish, V., Siva, K. V., Arockiarajan, A., & Tamadapu, G. (2022). Synthesis and characterization of hard magnetic soft hydrogels. *Materials Letters*, *320*, 132323.

Martinez-Balmori, D., Spaccini, R., Aguiar, N. O., Novotny, E. H., Olivares, F. L., & Canellas, L. P. (2014). Molecular characteristics of humic acids isolated from vermicomposts and their relationship to bioactivity. *Journal of Agricultural and Food Chemistry,* 62(47), 11412-11419.

Masood, S., & Bano, A. (2016). Mechanism of potassium solubilization in the agricultural soils by the help of soil microorganisms. Potassium solubilizing microorganisms for sustainable agriculture, 137-147.

Manish, V., Chelvane, J. A., Tamadapu, G., & Arockiarajan, A. (2023). Synthesis and characterization of gelatin-based hybrid magnetic hydrogels. *Materials Letters*, *345*, 134480.

Meena, B. S., Narolia, R. S., Meena, L. K., Meena, K. C., & Meena, S. N. (2020). Evaluation of hydrogel and salicylic acid application effect on yield, quality, economics and water-use efficiency of Indian mustard (*Brassica juncea*) in restricted irrigation condition of SE Rajasthan.). *International Journal of Current Microbiology and Applied Sciences*, 9, 3274-3283.

Meena, K., Meena, R. K., Meena, D. S., Meena, B. S., Meena, C. B., Yadav, V. K., & Jadon, C. K. (2023). Effect of inorganic fertilizers and biofertilizers on growth and nodulation of soybean [*Glycine max* (L.) Merrill]. 12(7), 1752-1755.

Meena, M. D., Tiwari, D. D., Chaudhari, S. K., Biswas, D. R., Narjary, B., Meena, A. L., ... & Meena, R. B. (2013). Effect of biofertilizer and nutrient levels on yield and nutrient uptake by maize (*Zea mays* L.). *Annals of Agri-Bio Research*, 18(2), 176-181.

Meena, R. P., Sharma, R. K., Tripathi, S. C., Chander, S., Chhokar, R. S., Meena, A., & Sharma, I. (2015). Influence of hydrogel, irrigation and nutrient levels on wheat productivity. *Journal of Wheat Research*, 7(2), 19-22.

Meganid, A. S., Al-Zahrani, H. S., & El-Metwally, M. S. (2015). Effect of humic acid application on growth and chlorophyll contents of common bean plants (*Phaseolus vulgaris* L.) under salinity stress conditions. International *Journal of Innovative Research in Science, Engineering and Technology*, 4(5), 2651-2660.

Meurer, R. A., Kemper, S., Knopp, S., Eichert, T., Jakob, F., Goldbach, H. E., Schwaneberg, U., & Pich, A. (2017). Biofunctional microgel-based fertilizers for controlled foliar delivery of nutrients to plants. *Angewandte Chemie International Edition*, 56(26), 7380-7386.

Mi, J., Gregorich, E. G., Xu, S., McLaughlin, N. B., Ma, B., & Liu, J. (2017). Effect of bentonite amendment on soil hydraulic parameters and millet crop performance in a semi-arid region. *Field Crops Research*, 212, 107-114.

Mishra, A. K., & Singh, V. P. (2011). Drought modeling–A review. Journal of Hydrology, 403(1-2), 157-175.

Mishra, D., Rajvir, S., Mishra, U., & Kumar, S. S. (2013). Role of bio-fertilizer in organic agriculture: a review. *Research Journal of Recent Sciences*, 2277, 2502.

Mishra, S., & Arora, N. K. (2012). Evaluation of rhizospheric Pseudomonas and Bacillus as biocontrol tool for *Xanthomonas campestris* pv campestris. *World Journal of Microbiology and Biotechnology*, 28, 693-702.

Moghadam, H. R. T., Khamene, M. K., & Zahedi, H. (2014). Effect of humic acid foliar application on growth and quantity of corn in irrigation withholding at different growth stages. Maydica, 59,124-128.

Mohammed, M. H., Meawad, A. A. A., El-Mogy, E. E. A. M., & Abdelkader, M. (2019). Growth, yield components and chemical constituents of Stevia rebaudiana Bert. as affected by humic acid and NPK fertilization rates. *Zagazig Journal of Agricultural Research,* 46(1), 13-26.

Mohan, M., Khajanji, S. N., & Pandey, N. (2021). Effect of crop geometry and integrated nutrient management in influencing growth and yield of winter season baby corn. *The Pharma Innovation Journal*, 10(9), 253-255.

Mohawesh, O., & Durner, W. (2019). Effects of bentonite, hydrogel and biochar amendments on soil hydraulic properties from saturation to oven dryness. *Pedospher*e, 29(5), 598-607.

Ahmed. A.A.M., Ibraheim, S. K. A., & Abdel-Fattah, M. K. (2022). Effect of potassium humate, nitrogen bio fertilizer and molybdenum on growth and productivity of garlic (*Allium sativum* L.). *Current Science International*, *6*(1): 75-85.

Moser, S. B., Feil, B., Jampatong, S., & Stamp, P. (2006). Effects of pre-anthesis drought, nitrogen fertilizer rate, and variety on grain yield, yield components, and harvest index of tropical maize. *Agricultural Water Management*, 81(1-2), 41-58.

Mtaita, T. A., Nyaera, K., Mutetwa, M., & Masaka, T. (2019). Effect of bio fertilizer with varying levels of mineral fertilizer on maize (*Zea mays*. L) growth. Galore *International Journal of Applied Sciences & Humanities*, 3(4), 1-9.

Mukherjee, A., Gaurav, A. K., Singh, S., Yadav, S., Bhowmick, S., Abeysinghe, S., & Verma, J. P. (2022). The bioactive potential of phytohormones: A review. *Biotechnology Reports*, 35, e00748.

Mushtaq, N., Singh, D. V., Bhat, R. A., Dervash, M. A., & Hameed, O. B. (2020). Freshwater contamination: sources and hazards to aquatic biota. *Fresh Water Pollution Dynamics and Remediation*, 27-50.

Nacoon, S., Jogloy, S., Riddech, N., Mongkolthanaruk, W., Kuyper, T. W., & Boonlue, S. (2020). Interaction between phosphate solubilizing bacteria and arbuscular mycorrhizal fungi on growth promotion and tuber inulin content of *Helianthus tuberosus* L. *Scientific reports*, 10(1), 4916.

Nadeem, S. M., Zahir, Z. A., Naveed, M., & Arshad, M. (2007). Preliminary investigations on inducing salt tolerance in maize through inoculation with rhizobacteria containing ACC deaminase activity. *Canadian Journal of Microbiology*, 53(10), 1141-1149.

Nand, V. (2015). Effect of spacing and fertility levels on protein content and yield of hybrid and composite maize (*Zea mays* L.) grown in rabi season. *Journal of Agriculture and Veterinary Science*, 8(9), 26-31.

Nardi, S., Schiavon, M., & Francioso, O. (2021). Chemical structure and biological activity of humic substances define their role as plant growth promoters. *Molecules*, 26(8), 2256.

Narjary, B., & Aggarwal, P. (2014). Evaluation of soil physical quality under amendments and hydrogel applications in a soybean–wheat cropping system. *Communications in Soil Science and Plant Analysis*, 45(9), 1167-1180.

Narjary, B., Aggarwal, P., Singh, A., Chakraborty, D., & Singh, R. (2012). Water availability in different soils in relation to hydrogel application. *Geoderma*, 187, 94-101.

Nasiroleslami, E., Mozafari, H., Sadeghi-Shoae, M., Habibi, D., & Sani, B. (2021). Changes in yield, protein, minerals, and fatty acid profile of wheat (*Triticum aestivum* L.) under fertilizer management involving application of nitrogen, humic acid, and seaweed extract. *Journal of Soil Science and Plant Nutrition*, 21(4), 2642-2651.

Neethu, T. M., Dubey, P. K., & Kaswala, A. R. (2018). Prospects and applications of hydrogel technology in agriculture. *International Journal of Current Microbiology and Applied Sciences*, 7(5), 3155-3162.

Nektarios, P. A., Nikolopoulou, A. E., & Chronopoulos, I. (2004). Sod establishment and turfgrass growth as affected by urea–formaldehyde resin foam soil amendment. *Scientia Horticulturae*, 100(1-4), 203-213.

Nogot, A., Khardi, A., Aboumadane, H., Goutoutou, M., & Jaiti, F. (2024). Enhancing Growth and Nutrient Uptake in Bouffegous Date Palm Variety With Seaweed Extracts and AMF/PGPR Combination in the Field. *AGBIR*, 40(3),1072-1077.

Noppakundilograt, S., Pheatcharat, N., & Kiatkamjornwong, S. (2015). Multilayer-coated NPK compound fertilizer hydrogel with controlled nutrient release and water absorbency. *Journal of Applied Polymer Science*, 132(2).

Oladosu, Y., Rafii, M. Y., Samuel, C., Fatai, A., Magaji, U., Kareem, I., Kamarudin, Z.S, Muhammad, I. & Kolapo, K. (2019). Drought resistance in rice from conventional to molecular breeding: a review. International journal of molecular sciences, 20(14), 3519.

Olaetxea, M., Mora, V., Baigorri, R., Zamarreño, A. M., & García-Mina, J. M. (2020). The singular molecular conformation of humic acids in solution influences their ability to enhance root hydraulic conductivity and plant growth. *Molecules*, 26(1), 3.

Olk, D. C., Dinnes, D. L., Rene Scoresby, J., Callaway, C. R., & Darlington, J. W. (2018). Humic products in agriculture: potential benefits and research challenges—a review. *Journal of Soils and Sediments*, 18, 2881-2891.

Olsen, S. R., Cole, C.V. & Watanabe, F.S. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United States Department of Agriculture, Circular, 939, 1-19.

Panchal, B. H., Patel, V. K., Patel, K. P., & Khimani, R. A. (2018). Effect of biofertilizers, organic manures and chemical fertilizers on microbial population, yield and yield attributes and quality of sweetcorn (*Zea mays* L., saccharata) cv. Madhuri. *International Journal of Current Microbiology and Applied Sciences*, 7(09), 2423-2431.

Panwar, J., & Laxmi, V. (2005). Biological nitrogen fixation in pulses and cereals. Developments in physiology, biochemistry and molecular biology of plants, (Ed. Bose B. & Hemantaranjan A.) Published by New India Publishing Agency, New Delhi,1, 125-158.

Parajuli, S., Shrestha, J., & Ghimire, S. (2020). Organic farming in Nepal: A viable option for food security and agricultural sustainability. *Archives of Agriculture and Environmental Science*, 5(2), 223-230.

Parihar, C. M., Jat, S. L., Singh, A. K., Kumar, R. S., Hooda, K. S., GK, C., & Singh, D. K. (2011). Maize production technologies in India. DMR Technical Bulletin2011/---. Directorate of Maize Research, Pusa Campus, New Delhi-110 012. Pp 30.

Parmar, P. M., Shroff, J. C., & Shah, S. N. (2023). Effect of cotton-legume intercropping patterns and crop geometry on growth and yield of Bt cotton. *The Pharma Innovation Journal,* 12(12): 2221-2228.

Parmar, P., & Sindhu, S. S. (2013). Potassium solubilization by rhizosphere bacteria: influence of nutritional and environmental conditions. *Journal of Microbiology Research*, 3(1), 25-31.

Pascoli, M., Jacques, M. T., Agarrayua, D. A., Avila, D. S., Lima, R., & Fraceto, L. F. (2019). Neem oil based nanopesticide as an environmentally-friendly formulation for applications in sustainable agriculture: An ecotoxicological perspective. *Science of the Total Environment*, 677, 57-67.

Patel, K. K., Shah, A. K., & Latare, A. M. (2023). Effects of Hydrogel on Physical and Chemical Properties of Soil. *International Journal of Plant & Soil Science*, 35(8), 129-135.

Patil, B., Kumar, V., & Merwade, M. N. (2018). Effect of inter row spacing and fertilizer levels on crop growth, seed yield and seed quality of perennial fodder sorghum cv. CoFS-29. *Range Management and Agroforestry*, 39(1), 59-64.

Pedrini, S., Merritt, D. J., Stevens, J., & Dixon, K. (2017). Seed coating: science or marketing spin?. Trends in plant science, 22(2), 106-116.

Pereira, J. W., AlbuquerqueMelo Filho, P., Albuquerque, M. B., Nogueira, R. M., & Santos, R. C. (2012). Biochemical changes in peanut genotypes submitted to moderate water stress. *Revista Ciência Agronômica*, 43(4), 766-773.

Pereyra, M. A., & Creus, C. M. (2017). Modifying the rhizosphere of agricultural crops to improve yield and sustainability: Azospirillum as a model rhizotroph. Rhizotrophs: Plant growth promotion to bioremediation, 15-37.

Portieles, R., Xu, H., Yue, Q., Zhao, L., Zhang, D., Du, L., ... & Borrás-Hidalgo, O. (2021). Heat-killed endophytic bacterium induces robust plant defense responses against important pathogens. *Scientific Reports*, 11(1), 12182.

Prayogo, C., Prasetya, B., & Arfarita, N. (2021). Comparative effects of the combination of biofertilizer, NPK, and mycorrhizal application on maize production system. In *IOP Conference Series: Earth and Environmental Science* (Vol. 905, No. 1, p. 012003). IOP Publishing.

Prisa, D., & Guerrini, G. (2023). Innovative hydrogels use in the germination and growth of tree species *Paulownia tomentosa* and *Cupressus sempervirens*. *GSC Advanced Research and Reviews*, 14(2), 121-128.

Pukalchik, M., Kydralieva, K., Yakimenko, O., Fedoseeva, E., & Terekhova, V. (2019). Outlining the potential role of humic products in modifying biological properties of the soil—a review. *Frontiers in Environmental Science*, 7, 80.

Qodliyati, M., & Nyoto, S. (2018, March). Influence of spacing and depth of planting to growth and yield of arrowroot (*Marantha arundinacea*). *In IOP Conference Series: Earth and Environmental Science* (Vol. 142, No. 1, p. 012035). IOP Publishing.

Radian, R., Ichwan, B., & Hayat, I. (2022). Nanotechnology for dryland agriculture water saving: Biodegradable hydrogel application in sweet corn (*Zea mays saccharate* Sturt) productio. *Emirates Journal of Food and Agriculture*. 34(9), 800-805.

Rajanna, G. A., Manna, S., Singh, A., Babu, S., Singh, V. K., Dass, A., ... & Parmar, B. S. (2022). Biopolymeric superabsorbent hydrogels enhance crop and water productivity of soybean–wheat system in Indo-Gangetic plains of India. *Scientific Reports*, 12(1), 11955.

Rajavarthini, R., & Kalyanasundaram, D. (2022). Studies on the effect of irrigation management and other agronomic practices on growth and yield characters of hybrid maize (*Zea mays* L.). *The Pharma Innovation*, 11(11), 1389-1395.

Rajkumar, M., Ae, N., Prasad, M. N. V., & Freitas, H. (2010). Potential of siderophore-producing bacteria for improving heavy metal phytoextraction. *Trends in Biotechnology,* 28(3), 142-149.

Ramegowda, V., & Senthil-Kumar, M. (2015). The interactive effects of simultaneous biotic and abiotic stresses on plants: mechanistic understanding from drought and pathogen combination. *Journal of Plant Physiology*, 176, 47-54.

Ramesh, B., & Chhabra, V. (2023). Effect of Integrated Nutrient Management on Growth and Yield Parameters of Maize (*Zea mays*.) (Poaceae). *International Journal of Environment and Climate Change*, 13(8), 874-880.

Rani, C. S., Sudhakar, C., & Rani, K. S. (2006). Effect of different spacings within a pair and between pairs on growth and productivity of pigeon pea crop [*Cajanus cajan* (L.) Mill sp.] in a paired row planting system. Education, International Journal of Agricultural Science and Research, 10(1), 1-6.

Rasadaree, T. S., Herath, H. M. I. K., Dedduwakumara, H. T., Kottegoda, N., & Kuruwita-mudiyanselage, T. (2021). Impact of Hydrogels on Early Growth of Maize in Sandy Regosols: Progress towards Improving Growth Performance by Enhancing Water and Nutrients Retention Capacity of the Soil. *Journal of Food and Agriculture*, 14(1), 36-48.

Ravier, I., Haouisee, E., Clément, M., Seux, R., & Briand, O. (2005). Field experiments for the evaluation of pesticide spray-drift on arable crops. *Pest Management Science*: formerly Pesticide Science, 61(8), 728-736.

Reddy, M. V. R., Singh, R., & Khan, W. (2020). Agronomic evaluation of spacing and nitrogen management practices on growth and yield of sesame (*Sesamum indicum* L.). *Asian Journal of Microbiology, Biotechnology and Environmental Sciences*, 23(2), 225-230.

Reddy, S. R. P. K., Debbarma, V., & Reddy, K. (2023). Influence of Biofertilizers and Organic Liquid Nutrients on Growth, Yield and Economics of Maize (*Zea mays* L.). *International Journal of Environment and Climate Change*, 13(7), 724-731.

Reed, S. C., Cleveland, C. C., & Townsend, A. R. (2011). Functional ecology of free-living nitrogen fixation: a contemporary perspective. *Annual review of Ecology, Evolution, and Systematics*, 42, 489-512.

Rehman, A., Ahmad, R., & Safdar, M. (2011). Effect of hydrogel on the performance of aerobic rice sown under different techniques. *Plant, Soil and Environment*, 57(7), 321-325.

Riad, G. S., Youssef, S. M., El-Azm, N. A. I. A., & Ahmed, E. M. (2018). Amending sandy soil with biochar or/and superabsorbent polymer mitigates the adverse effects of drought stress on green pea. *Egyptian Journal of Horticulture*, 45(1), 169-183.

Rizwan, M., Gilani, S. R., Durani, A. I., & Naseem, S. (2021). Materials diversity of hydrogel: Synthesis, polymerization process and soil conditioning properties in agricultural field. *Journal of Advanced Research*, 33(2), 15-40.

Rokhminarsi, E., & Utami, D. S. (2019). Application of Mikotricho (Mycorrhizae-Trichoderma) Fertilizer and Synthetic Fertilizer on Cultivation of Red Pepper. *Jurnal Hortikultura Indonesia,* 10(3), 154-160.

Rose, M. T., Patti, A. F., Little, K. R., Brown, A. L., Jackson, W. R., & Cavagnaro, T. R. (2014). A meta-analysis and review of plant-growth response to humic substances: practical implications for agriculture. *Advances in Agronomy*, 124, 37-89.

Roshan, A., & Verma, N. K. (2015). A brief study on neem (*Azarrdirachta indica* A.) and its application–A review. *Research Journal of Phytomedicine*, 1(1), 01-03.

Rosmaina, Utami, D., Aryanti, E., & Zulfahmi. (2021). Impact of heat stress on germination and seedling growth of chili pepper (Capsicum annuum L.). 637: 012032**.**

Roy, S., Liu, W., Nandety, R. S., Crook, A., Mysore, K. S., Pislariu, C. I., ... & Udvardi, M. K. (2020). Celebrating 20 years of genetic discoveries in legume nodulation and symbiotic nitrogen fixation. *The Plant Cell*, 32(1), 15-41.

Roy, T., Kumar, S., Chand, L., Kadam, D. M., Bihari, B., Shrimali, S. S., ... & Mallik, A. (2019). Impact of Pusa hydrogel application on yield and productivity of rainfed wheat in North West Himalayan region. *Current Science*, 116(7), 1246-1251.

Rupiasih, N. N., & Vidyasagar, P. (2005). A review: Compositions, structures, properties and applications of humic substances. *Journal of Advanced Science and Technology*, 8, 16-25.

Sabur, A., Pramudyani, L., Yasin, M., & Purnomo, J. (2021). Application of biological fertilizers on growth and yield of sweet corn (*Zea mays* saccharata Sturt) in dry land. In *IOP Conference Series: Earth and Environmental Science* (Vol. 807, No. 4, p. 042024). IOP Publishing.

Sagar, R., Kadalli, G. G., Vivek, M. S., & Irfan, M. M. (2020). Impact of Disparate Levels of Humic Substance Enriched with Micronutrients on Productivity and Cultivation Economics of Maize. *International Journal of Current Microbiology and Applied Sciences,* 10, 521-532.

Sahoo, R. K., Bhardwaj, D., & Tuteja, N. (2012). Biofertilizers: a sustainable eco-friendly agricultural approach to crop improvement. In Plant acclimation to environmental stress (pp. 403-432). New York, NY: Springer New York.

Saini, V., Berwal, R., Sharma, J., & Singh, A. (2004). Biofertilizers: Current status and perspectives in agriculture. *Pollution Research*, 23(4), 665-676.

Salem, T., Refaie, K., Al-Mushhin, A., & Saad, S. (2023). Magnetic Nanoparticles-Grafted-Poly (Acrylic acid) as a Super-Hydrogel composite: Preparation, Characterization and application in agriculture. *Asian Journal of Plant Sciences*, 22(1), 56–65.

Samson, M. F., Mabille, F., Chéret, R., Abécassis, J., & Morel, M. H. (2005). Mechanical and physicochemical characterization of vitreous and mealy durum wheat endosperm. *Cereal Chemistry*, 82(1), 81-87.

Sandhu, N., Sethi, M., Kumar, A., Dang, D., Singh, J., & Chhuneja, P. (2021). Biochemical and genetic approaches improving nitrogen use efficiency in cereal crops: A review. *Frontiers in Plant Science*, 12, 657629.

Sangeeta, H. P., Patel, J. R., Agrawal, A. P., Sharma, G., Chaure, N. K., Patel, C. R., Patel, C.R., Patel, M.K., Laxmi, S., & Chhabra, M. (2023). Effect of crop geometry and weed management on growth, yield attributes and yield of rice (*Oryza sativa* L.). *The Pharma Innovation Journal*, 12(12): 246-251.

Santosh, S., Velmourougane, K., Idapuganti, R. G., Manikandan, A., & Blaise, D. (2022). Potassium solubilizing potential of native bacterial isolates from cotton rhizosphere of rainfed vertisols. *National Academy Science Letters*, 45(3), 209-212.

Santoyo, G., Guzmán-Guzmán, P., Parra-Cota, F. I., Santos-Villalobos, S. D. L., Orozco-Mosqueda, M. D. C., & Glick, B. R. (2021). Plant growth stimulation by microbial consortia. *Agronomy,* 11(2), 219.

Sapkota, T. B., Jat, M. L., Stirling, C. M., Jat, H. S., Majumdar, K., Sidhu, H. S., & Jat, R. K. (2018, December). Climate smart fertilizer management in smallholder cereal systems: examples of precision nutrient management in smallholder cereal systems across Indo-Gangetic Plains of India. In AGU Fall Meeting Abstracts (Vol. 2018, pp. GC22B-05B).

Sasmal, P. K., & Patra, S. (2022). Effect in growth of corn plant from cellulose-based hydrogel derived from wheat straw. *Journal of The Institution of Engineers (India): Series* E, 103(1), 41-46.

Sathyan, T., Elanchezhyan, K., & Murugesan, N. (2020). Pests of black pepper and their management. *Biotica Research Today*, 2(4), 87-89.

Satriani, A., Catalano, M., & Scalcione, E. (2018). The role of superabsorbent hydrogel in bean crop cultivation under deficit irrigation conditions: A case-study in Southern Italy. *Agricultural Water Management*, 195, 114-119.

Savy, D., Canellas, L., Vinci, G., Cozzolino, V., & Piccolo, A. (2017). Humic-like water-soluble lignins from giant reed (*Arundo donax* L.) display hormone-like activity on plant growth. *Journal of Plant Growth Regulation*, 36, 995-1001.

Saxena, A., Upadhyay, T., Rai, D., & Kalra, A. (2021). Hydrogels: An innovative polymer for water conservation in wheat (*Triticum aestivum* L.). *Advances in Agriculture, Horticulture and Entomology,* 163: 07.

Schacht, E. H. (2004). Polymer chemistry and hydrogel systems. *In Journal of Physics: Conference Series*, 3(1): 22-28.

Schmidt, W., Santi, S., Pinton, R., & Varanini, Z. (2007). Water-extractable humic substances alter root development and epidermal cell pattern in Arabidopsis. *Plant and Soil*, 300, 259-267.

Seenivasagan, R., & Babalola, O. O. (2021). Utilization of microbial consortia as biofertilizers and biopesticides for the production of feasible agricultural product. *Biology*, 10(11), 1111.

Seran, T. H., & Brintha, I. (2009). Study on determining a suitable pattern of capsicum (*Capsicum annum* L.)-vegetable cowpea (*Vigna unguiculata* L.) intercropping. *Karnataka Journal of Agricultural Sciences*, 22(5), 1153-1154.

Sharma, J. (2004). Establishment of perennials in hydrophilic polymer-amended soil. *In SNA Research Conference,* 42:530-32.

Sharma, M., Singh, O., Singh, G., & Kaur, G. (2014). A snap shot of spring maize cultivation in Kapurthala and Jalandhar districts under central plain zone of Punjab. *Journal of Krishi Vigyan,* 3(1), 1-4.

Sharma, N., Khanna, K., Manhas, R. K., Bhardwaj, R., Ohri, P., Alkahtani, J., Mona, S., & Ahmad, P. (2020). Insights into the role of Streptomyces hydrogenans as the plant growth promoter, photosynthetic pigment enhancer and biocontrol agent against Meloidogyne incognita in *Solanum lycopersicum* seedlings. *Plants*, 9(9), 1109.

Sharma, P., Bisen, B. P., Tiwari, A., & Rai, H. K. (2023). Effect of super absorbent polymer and mulching on morpho-phenological and yield characteristics of cucumber (*Cucumis sativus* L.). *The Pharma Innovation Journal*, 12(2), 1828-1833.

Sharma, S. B., Sayyed, R. Z., Trivedi, M. H., & Gobi, T. A. (2013). Phosphate solubilizing microbes: sustainable approach for managing phosphorus deficiency in agricultural soils. Springer Plus, 2, 1-14.

Shen, J., Guo, M., Wang, Y., Yuan, X., Dong, S., Song, X. E., & Guo, P. (2020). An investigation into the beneficial effects and molecular mechanisms of humic acid on foxtail millet under drought conditions. *PLoS One*, 15(6), e0234029.

Shivakumar, R., Bridgit, T. K., & Retheesh, P. K. (2019). Effect of hydrogel and mulching on yield, yield attributes and economics of maize (*Zea mays* L.) In sandy soil. *International Journal of Chemical Studies*, 7(3), 2011-2015.

Shubhadarshi, S., & Kukreja, S. (2020). Hydrogel: Promising alternative for water and nutrient management. *International Journal of Chemical Studies*, 8(6), 354-358.

Sible, C. N., Seebauer, J. R., & Below, F. E. (2021). Plant biostimulants: A categorical review, their implications for row crop production, and relation to soil health indicators. *Agronomy*, 11(7), 1297.

Silva, M. S., Broglio, S. M. F., Trindade, R. C. P., Ferrreira, E. S., Gomes, I. B., & Micheletti, L. B. (2015). Toxicity and application of neem in fall armyworm. *Comunicata Scientiae*, 6(3), 359-364.

Singh, D. V., Bhat, R. A., Dervash, M. A., Qadri, H., Mehmood, M. A., Dar, G. H., ... & Rashid, N. (2020). Wonders of nanotechnology for remediation of polluted aquatic environs. *Fresh Water Pollution Dynamics and Remediation*, 319-339.

Singh, M. K., Srivastava, N., & Singh, R. K. (2017). Integrated effect of biofertilizers and inorganic fertilizers on growth, yield and quality of onion (*Allium cepa* L.). *Journal of Pharmacognosy and Phytochemistry*, 6(5), 1841-1844.

Singh, M., Dotaniya, M. L., Mishra, A., Dotaniya, C. K., Regar, K. L., & Lata, M. (2016). Role of biofertilizers in conservation agriculture. Conservation agriculture: an approach to combat climate change in Indian Himalaya, 113-134.

Singh, R., Singh, Y., & Singh, S. (2017). Yield, quality and nutrient uptake of Indian mustard (*Brassica juncea*) under sulphur and boron nutrition. *Annals of Plant and Soil Research*, 19(2), 227-231.

Singh, T., & Sandhu, P. S. (2020). Strategies for mitigation of moisture stress in maize (*Zea mays* L.)-A Review. *Chemical Science Review and Letters*, 9(35), 798-814.

Sivamurugan, A. P., Ravikesavan, R., Singh, A. K., & Jat, S. L. (2018). Effect of different levels of P and liquid biofertilizers on growth, yield attributes and yield of maize. *Chemical Science Review and Letters*, 7, 520-523.

Sivapalan, S. (2001). Effect of a polymer on growth and yield of soybeans (*Glycine max*) grown in a coarse textured soil. *In Irrigation 2001 Regional Conference,* pp. 93-99.

Soumare, A., Diedhiou, A. G., Thuita, M., Hafidi, M., Ouhdouch, Y., Gopalakrishnan, S., & Kouisni, L. (2020). Exploiting biological nitrogen fixation: a route towards a sustainable agriculture. *Plants*, 9(8), 1011.

Sreethu, S., Chhabra, V., Kaur, G., & Ali, B. (2024). Biofertilizers as a Greener Alternative for Increasing Soil Fertility and Improving Food Security Under Climate Change Condition. Communications in Soil Science and Plant Analysis, 55(2), 261-285.

Srilathavani, C.H., Rao I.V.Y.R., & Lakshmi, M. B., (2020) Paired Row Planting in Sugarcane-Multi-Dimensional Analysis. *International Journal of Agriculture Sciences,* 12(22), 10383-10385.

Stewart, W. M., & Roberts, T. L. (2012). Food security and the role of fertilizer in supporting it. *Procedia Engineering*, 46, 76-82.

Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. Current Science, 25, 259-260.

Sujayanand, G. K., Akram, M., Konda, A., Nigam, A., Bhat, S., Dubey, J., ... & Muthusamy, S. K. (2021). Distribution and toxicity of Bacillus thuringiensis (Berliner) strains from different crop rhizosphere in Indo-Gangetic plains against polyphagous lepidopteran pests. *International Journal of Tropical Insect Science*, 1-19.

Sumbul, A., Ansari, R. A., Rizvi, R., & Mahmood, I. (2020). Azotobacter: A potential bio-fertilizer for soil and plant health management. *Saudi Journal of Biological Sciences*, 27(12), 3634-3640.

Suresh, R., Prasher, S. O., Patel, R. M., Qi, Z., Elsayed, E., Schwinghamer, T., & Ehsan, A. M. (2018). Super absorbent polymer and irrigation regime effects on growth and water use efficiency of container-grown cherry tomatoes. *Transactions of the ASABE (American Society of Agricultural and Biological Engineers),* 61(2), 523-531.

Talwar, D., Singh, K., & Singh, J. (2017). Effect of biofertilizers on soil microbial count, nutrient availability and uptake under November sown onion. *Journal of Applied and Natural Science,* 9(1), 55-59.

Tandon, M., Meshram, Y. K., & Dixit, R. (2021). Comparative study of PSB and NPK consortia affecting the yield attributes of hybrid maize. *International Journal of Agricultural sciences*, 17(2), 409-412.

Tantray, A. Y., Hazzazi, Y., & Ahmad, A. (2022). Physiological, agronomical, and proteomic studies reveal crucial players in rice nitrogen use efficiency under low nitrogen supply. *International Journal of Molecular Sciences*, 23(12), 6410.

Tanwar, S. P. S., Sharma, G. L., & Chahar, M. S. (2003). Effect of phosphorus and biofertilizers on yield, nutrient content and uptake by black gram [*Vigna mungo* (L.) Hepper]. *Legume Research-An International Journal*, 26(1), 39-41.

Tavares, O. C. H., Santos, L. A., de Araújo, O. J. L., Bucher, C. P. C., García, A. C., Arruda, L. N., ... & Fernandes, M. S. (2019). Humic acid as a biotechnological alternative to increase N-NO3-or N-NH4+ uptake in rice plants. *Biocatalysis and agricultural biotechnology*, 20, 101226.

Tenreiro, T. R., García-Vila, M., Gómez, J. A., Jimenez-Berni, J. A., & Fereres, E. (2020). Water modelling approaches and opportunities to simulate spatial water variations at crop field level. *Agricultural Water Management*, 240, 106254.

Thakur, S., Jha, S.K., Kumar, S., Shesh, J., & Naya, N. (2020). Effect of crop geometry and nitrogen levels on growth, productivity of baby corn (*Zea mays* L.). *International Journal of Research in Agronomy*, 3(2), 55-57.

Thamatam, S., & Mehera, B. (2022). Effect of bio fertilizers and zinc on growth and yield of sweet corn. *The Pharama Innovation Journal*, 11(4), 1255-1257.

Thangarajan, R., Bolan, N. S., Kunhikrishnan, A., Wijesekara, H., Xu, Y., Tsang, D. C., ... & Hou, D. (2018). The potential value of biochar in the mitigation of gaseous emission of nitrogen. *Science of the Total Environment*, 612, 257-268.

Thejesh, C., Singh, S., Reddy, K. S., Mathpal, B. (2024). Efficacy of Different Levels of Hydrogel and Crop Geometric Strategies in Overcoming the Pessimistic Effect of Abiotic Stress on Growth and Yield Attributes of Spring Maize (*Zea mays* L.). *Indian Journal of Agricultural Research,* 58(3), 398-406.

Thejesh, C., Maheshwara, C., & Dawson, J. (2020). Studies on Growth, Yield and Economics of rice (*Oryza sativa*. L) var. Pusa Basmati-1 as Influenced by Biofertilizers. *International Journal of Current Microbiology and Applied Sciences*, 9(6), 86-97.

Thenua, O. V. S., & Ravindra, K. (2011). Effect of phosphorus, sulphur and phosphate solubilizing bacteria on productivity and nutrient uptake of chickpea. *Annals of Agricultural Research,* 32(3&4), 116-119.

Tian, J., Ge, F., Zhang, D., Deng, S., & Liu, X. (2021). Roles of phosphate solubilizing microorganisms from managing soil phosphorus deficiency to mediating biogeochemical P cycle. *Biology*, 10(2), 158.

Tiwari, A.K., Prakash, V., Ahmad, A., & Singh, R.P. (2018). Effect of Biofertilizers and Micronutrients on Nutrient Uptake, Growth, Yield and Yield Attributes of Lentil

(*Lens culinaris* L.*). International Journal of Current Microbiology and Applied Sciences,* 7(02), 3269-3275.

Tripathi, A., Gupta, S., Singh, A. K., Mishra, H., & Tripathi, S. (2023). Effect of irrigation scheduling and hydrogel level on growth and yield of wheat (*Triticum aestivum* L.). *The Pharma Innovation Journal*, 12(6), 4934-4937.

Tyagi, V., Singh, R. K., & Nagargade, M. (2015). Effect of hydrogel, NPK and irrigation levels on yield, nutrient uptake and water use efficiency of wheat (Triticum aestivum L.). *Research on Crops*, *16*(4), 653-656.

Tyagi, S., Kumar, R., & Kumar, B. (2018). Evaluation of water retaining granules on winter maize (Zea mays L.) under supplemental irrigation. *Journal of Pharmacognosy and Phytochemistry*, 7(1S), 1244-1248.

United Nations Environment Programme, (2012). Neem: The UN's tree of the 21st century. Nairobi: United Nations Environment Programme. Retrieved from website. .http://www.unep.org/wed/tree-a-day/neem.asp

United Nations. (2017). World Population Prospects: The 2017 Revision. Retrieved from website: https://www.un.org/en/desa/world-population-projected-reach-98-billion-2050-and-112-billion-2100\

Uphoff, N. T., Marguerite, J. D., Bahera, D., Verma, A. K., & Pandian, B. J. (2011). National colloquium on system of crop intensification (SCI). Field immersion of system of crop intensification (SCI), Patna, 57.

Utami, D., & Aryanti, E. (2021). Impact of heat stress on germination and seedling growth of chili pepper (*Capsicum annuum* L.). In *IOP Conference Series: Earth and Environmental Science* (Vol. 637, No. 1, p. 012032). IOP Publishing.

Varga, T., Hixson, K. K., Ahkami, A. H., Sher, A. W., Barnes, M. E., Chu, R. K., ... & Doty, S. L. (2020). Endophyte-promoted phosphorus solubilization in Populus. Frontiers in plant science, 11, 567918.

Venkatashwarlu, B. (2008). Role of bio-fertilizers in organic farming: Organic farming in rain fed agriculture: Central Institute for Dry land Agriculture. Hyderabad. India. pp, 85-95.

Verma, A. K., Sindhu, S. S., Anand, P., Singh, A., Chauhan, V. B. S., & Verma, S. K. (2018). Vermi products and biodegradable superabsorbent polymer improve physiological activities and leaf nutrient contents of gerbera. *Research Journal of Biotechnology*, 13(3), 8-18.

Vessey, J. K. (2003). Plant growth promoting rhizobacteria as biofertilizers. *Plant and Soil*, 255, 571-586.

Viero, P. W. M., Little, K. M., & Oscroft, D. G. (2000). The effect of a soil-amended hydrogel on the establishment of *a Eucalyptus grandis* x *E. camaldulensis* clone grown on the sandy soils of Zululand. *Southern African Forestry Journal*, 188(1), 21-28.

Vijayalakshmi, V., Nemichandrappa, M., Reddy, K. S., & Ayyanagowdar, M. S. (2013). Effect of polymers on moisture retention and soil water holding capacity. *Karnataka Journal of Agricultural Sciences*, 25(4),469-471.

Vishwakarma, K., Kumar, N., Shandilya, C., Mohapatra, S., Bhayana, S., & Varma, A. (2020). Revisiting plant–microbe interactions and microbial consortia application for enhancing sustainable agriculture: a review. *Frontiers in Microbiology*, 11, 560406.

Waghmare, P. K., Katkade, S. J., Bhalerao, G. A., & Narkhede, W. N.,2018. Effect of Different Crop Geometry on Growth, Yield and Economics of Bt Cotton. *International Journal of Current Microbiology and Applied Sciences,* (6s), 1222-1225.

Wahane, M. R., Meshram, N. A., More, S. S., & Khobragade, N. H. (2020). Biofertilizer and their role in sustainable agriculture-A Review. *The Pharma Innovation Journal*, 9(7), 127-130.

Walkley, A. & Black, I.A. (1934) An Examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, 37, 29-38.

Wang, H. Y., Shen, L. I. U., Zhai, L. M., Zhang, J. Z., Ren, T. Z., Fan, B. Q., & LIU, H. B. (2015). Preparation and utilization of phosphate biofertilizers using agricultural waste. *Journal of Integrative Agriculture*, 14(1), 158-167.

Wang, H., Wang, Y., Jiang, D., Xiang, Z., Wang, S., Kang, C., ... & Guo, L. (2022). Soil microbe inoculation alters the bacterial communities and promotes root growth of Atractylodes lancea under heat stress. *Plant and Soil*, 478(1), 371-389.

Wang, Y., Yang, Z., Kong, Y., Li, X., Li, W., Du, H., & Zhang, C. (2020). GmPAP12 is required for nodule development and nitrogen fixation under phosphorus starvation in soybean. *Frontiers in Plant Science*, 11, 450.

Wiesler, F., Hund-Rinke, K., Gäth, S., George, E., Greef, J. M., Hölzle, L. E., ... & Pietsch, M. (2016). Anwendung von organischen Düngern und organischen Reststoffen in der Landwirtschaft. 94,1.

Wilson, H. T., Amirkhani, M., & Taylor, A. G. (2018). Evaluation of gelatin as a biostimulant seed treatment to improve plant performance. *Frontiers in Plant Science*, 9, 1006.

Wu, S., Li, R., Peng, S., Liu, Q., & Zhu, X. (2017, June). Effect of humic acid on transformation of soil heavy metals. In IOP Conference Series: Materials Science and Engineering, 207,(1), 012089.

Wu, W., Du, K., Kang, X., & Wei, H. (2021). The diverse roles of cytokinins in regulating leaf development. Horticulture Research, 8, 118.

Xia, Y., Liu, J., Chen, C., Mo, X., Tan, Q., He, Y., ... & Zhou, G. (2022). The multifunctions and future prospects of endophytes and their metabolites in plant disease management. *Microorganisms*, 10(5), 1072.

Xu, S., Zhang, L., McLaughlin, N. B., Mi, J., Chen, Q., & Liu, J. (2015). Effect of synthetic and natural water absorbing soil amendment soil physical properties under potato production in a semi-arid region. *Soil and Tillage Research*, 148, 31-39.

Xu, S., Zhang, L., Zhou, L., Mi, J., McLaughlin, N. B., & Liu, J. (2018). Effect of water absorbing soil amendments on plant growth and soil chemical properties for potato production in a semi-arid region. *Agricultural Engineering International*: CIGR Journal, 20(2), 9-18.

Yadav, I. C., Devi, N. L., Syed, J. H., Cheng, Z., Li, J., Zhang, G., & Jones, K. C. (2015). Current status of persistent organic pesticides residues in air, water, and soil, and their possible effect on neighboring countries: A comprehensive review of India. *Science of the Total Environment*, 511, 123–137.

Yadav, K. K., & Smritikana Sarkar, S. S. (2019). Biofertilizers, impact on soil fertility and crop productivity under sustainable agriculture. *Environment & Ecology*, 37 (1), 89–93.

Yadav, S., Kumar, S., Anshuman, K., Singh, N., Srivastava, A., Yadav, D. K., & Dev, A. (2021). Studies on effect of different biofertilizers on nutrients availability and uptake of nutrients under chickpea crop. *The Pharma Innovation Journal*, 10(4): 546-549.

Yamaguchi, T., Takei, T., Yazawa, Y., Wong, M. T. F., Gilkes, R. J., & Swift, R. S. (2004). Effect of humic acid, sodium, and calcium additions on the formation of water-stable aggregates in Western Australian wheatbelt soils. *Soil Research*, 42(4), 435-439.

Yang, F., Tang, C., & Antonietti, M. (2021). Natural and artificial humic substances to manage minerals, ions, water, and soil microorganisms. *Chemical Society Reviews*, 50(10), 6221-6239.

Yang, F., Yuan, Y., Liu, Q., Zhang, X., Gai, S., Jin, Y., & Cheng, K. (2023). Artificial humic acid promotes growth of maize seedling under alkali conditions. *Environmental Pollution*, 327, 121588.

Yasuda, M., Dastogeer, K. M., Sarkodee-Addo, E., Tokiwa, C., Isawa, T., Shinozaki, S., & Okazaki, S. (2022). Impact of Azospirillum sp. B510 on the rhizosphere microbiome of rice under field conditions. *Agronomy*, 12(6), 1367.

Yazdani, F., Allahdadi, I., & Akbari, G. A. (2007). Impact of superabsorbent polymer on yield and growth analysis of soybean (*Glycine max* L.) under drought stress condition. Pakistan journal of biological sciences: *Pakistan Journal of Biological Sciences*, 10(23), 4190-4196.

Youssef, M. M. A., & Eissa, M. F. M. (2014). Biofertilizers and their role in management of plant parasitic nematodes. A review. *Journal of Biotechnology and Pharmaceutical Research*, 5(1), 1-6.

Yu, J., Shainberg, I., Yan, Y. L., Shi, J. G., Levy, G. J., & Mamedov, A. I. (2011). Superabsorbents and semiarid soil properties affecting water absorption. *Soil Science Society of America Journal*, 75(6), 2305-2313.

Yu, J., Shi, J. G., Dang, P. F., Mamedov, A. I., Shainberg, I., & Levy, G. J. (2012). Soil and polymer properties affecting water retention by superabsorbent polymers under drying conditions. *Soil Science Society of America Journal*, 76(5), 1758-1767.

Zahir, Z. A., Munir, A., Asghar, H. N., Shaharoona, B., & Arshad, M. (2008). Effectiveness of rhizobacteria containing ACC deaminase for growth promotion of peas (Pisum sativum) under drought conditions. *Journal of Microbiology and Biotechnology*, 18(5), 958-963.

Zhang, S. Q., Liang, Y., Wei, L., Lin, Z. A., Li, Y. HU, S. W., & Zhao, B. Q. (2019). Effects of urea enhanced with different weathered coal-derived humic acid components on maize yield and fate of fertilizer nitrogen. *Journal of Integrative Agriculture*, 18(3), 656-666.

APPENDICES

Appendix. 1. Weather conditions that prevailed throughout the cropping seasons of the experiment (spring seasons of 2022 and 2023).										
S. no	**Standard meteorological week (SMW)**	**Week**	**Maximum temperature ⁰C**		**Minimum temperature ⁰C**		**Total weekly rainfall (mm)**		**No. of rainy days per week**	
			2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
1	9	26 Feb – 04 Mar	17.1	27.4	9.3	14	16	0.02	1	1
2	10	05 Mar – 11 Mar	21.3	29.4	14.3	14	0	0	0	0
3	11	12 Mar – 18 Mar	26.9	27.8	19.8	16.7	0	15	0	1
4	12	19 Mar – 25 Mar	31.9	24.7	21.5	13.9	0	38.4	0	3
5	13	26 Mar – 01 Apr	31.4	27.6	21	15.7	0	2.22	0	2
6	14	02 Apr – 08 Apr	33.14	27.8	24.1	14.2	0	2.4	0	2
7	15	09 Apr – 15 Apr	41.29	35.5	27.1	16.1	0.5	0	1	0
8	16	16 Apr – 22 Apr	39.43	35.3	28.7	17.2	0	9.3	0	1
9	17	23 Apr – 29 Apr	41.14	35	30.9	18.2	0	0	0	0
10	18	30 Apr – 06 May	39.86	34	30	20.4	0	5.7	0	5
11	19	07 May – 13 May	40.14	40.5	31	23.2	0	0	0	0
12	20	14 May – 20 May	40.14	42.9	31.6	25.4	0	7.6	0	1
13	21	21 May – 27 May	40.14	37	28.1	22.2	11.2	14.2	1	2
14	22	28 May – 03 Jun	37.71	31.9	31.3	20.5	0	39.4	0	5
15	23	04 Jun – 10 Jun	41.29	37.6	32.1	22.1	0	23.6	0	3
16	24	11 Jun – 17 Jun	38.71	36.3	32	23.7	0	41.6	0	3
17	25	18 Jun – 24 Jun	39.71	37.9	29.6	27.6	70.6	16.2	2	1

Appendix. 2. Fixed costs (₹/ha) incurred during the experiment.					
S.no	**Operation**		**Quantity**	**Cost per quantity**	**Total** (₹/ha)
1	Land preparation (tractor ploughing and bunds)		3 hr	500	1500
2	Layout preparation		5 labours	450 per day	2250
3	Sowing and basal dose fertilizer application		10 labours	450 per day	4500
4	Fertilizer				
	N	Urea	261 kg/ha	268 per 50 kg/bag	1465
	P	SSP	333 kg/ha	362 per 50 kg/bag	2415
	K	MOP	67 kg/ha	872 per 50 kg/bag	1169
5	Labour for split dose		3 splits x 2 Labours per split (6)	450 per day	2700
6	Intercultural operations				
	Hand weeding		6 Labours	450 per day	2700
	Spraying	2 herbicides	2 Labour	450 per day	900
		2 plant protection chemicals	2 Labours	450 per day	900
7	Herbicides and plant protection chemicals		2 herbicides	350	700
			2 plant protection chemicals	450	900
8	Pheromone traps		10	56	560
9	Harvesting and shelling		10 labours x 2 days	450 per day	9000
10	Land lease and miscellaneous for cropping season		4 months	1000/months	4000
				Total	35659

Appendix. 3. Variable costs (₹/ha) of seed capsules and hydrogel incurred during the experiment.								
S. no	**Treatment combination**	**Seed quantity (kg/ha)**	**Seed cost per kg**	**Total seed cost (₹/ha)**	**Capsule cost (₹/ha)**	**Total seed capsule cost (₹/ha)**	**Dose of hydrogel (kg/ha)**	**Cost incurred with hydrogel (₹/ha)**
1	T_1	25	180	4500	0	4500	0	0
2	T_2	25	180	4500	0	4500	0	0
3	T_3	17.5	180	3150	9279	12429	0	0
4	T_4	17.5	180	3150	9279	12429	0	0
5	T_5	25	180	4500	0	4500	1.5	900
6	T_6	25	180	4500	0	4500	1.5	900
7	T_7	17.5	180	3150	9279	12429	1.5	900
8	T_8	17.5	180	3150	9279	12429	1.5	900
9	T_9	25	180	4500	0	4500	3	1800
10	T_{10}	25	180	4500	0	4500	3	1800
11	T_{11}	17.5	180	3150	9279	12429	3	1800
12	T_{12}	17.5	180	3150	9279	12429	3	1800

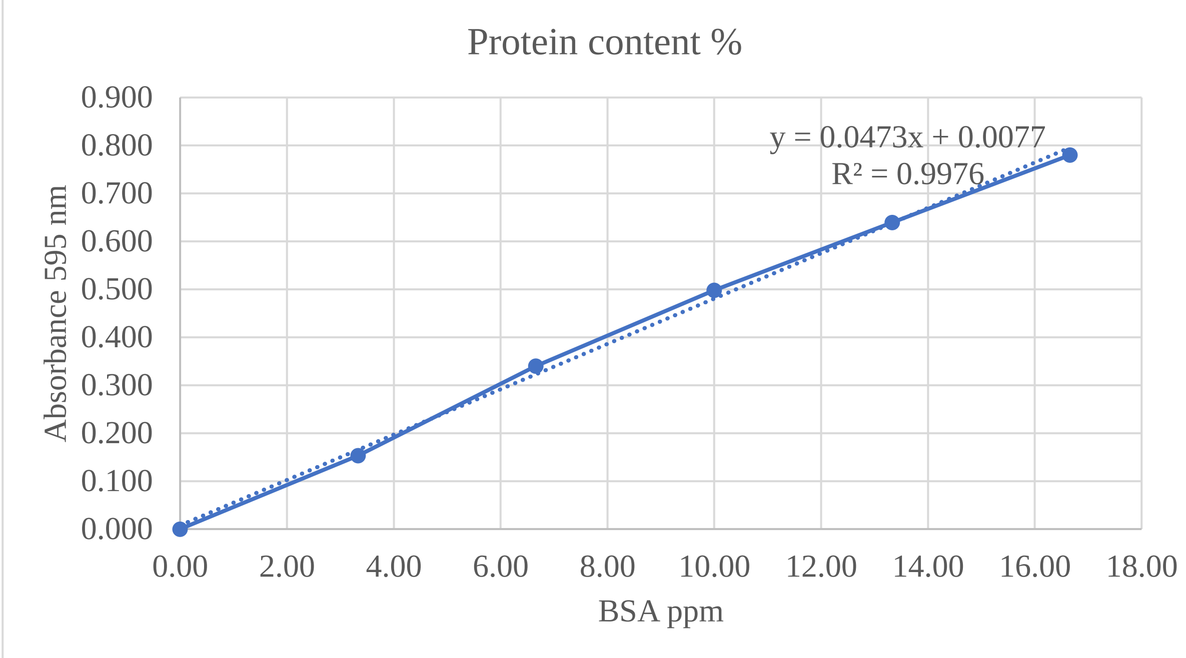
Appendix. 4. Variable costs (₹/ha) of irrigation incurred during the experiment.

		2022				2023		
S. no	**Treatment combination**	**No. of irrigations**	**Total man power**	**Total labour cost**	**No. of irrigations**	**Total man power**	**Labour cost/day**	**Total labour cost**
1	T1	13	26	11700	7	14	450	6300
2	T2	13	26	11700	7	14	450	6300
3	T3	13	26	11700	7	14	450	6300
4	T4	13	26	11700	7	14	450	6300
5	T5	11	22	9900	5	10	450	4500
6	T6	11	22	9900	5	10	450	4500
7	T7	11	22	9900	5	10	450	4500
8	T8	11	22	9900	5	10	450	4500
9	T9	8	16	7200	4	8	450	3600
10	T10	8	16	7200	4	8	450	3600
11	T11	8	16	7200	4	8	450	3600
12	T12	8	16	7200	4	8	450	3600
Labour cost - 450₹/day					**Electricity cost - 60 ₹/irrigation**			

Appendix. 5. Total cost of cultivation (₹/ha) incurred during the experiment in 2022.

S. no	Treatment combination	Fixed cost (₹/ha)	Variable cost (₹/ha)			Cost of cultivation (₹/ha)
			Seed capsule	Hydrogel	Irrigation labour	
1	T1	35659	4500	0	11700	52639
2	T2	35659	4500	0	11700	52639
3	T3	35659	12429	0	11700	60568
4	T4	35659	12429	0	11700	60568
5	T5	35659	4500	900	9900	51619
6	T6	35659	4500	900	9900	51619
7	T7	35659	12429	900	9900	59548
8	T8	35659	12429	900	9900	59548
9	T9	35659	4500	1800	7200	49639
10	T10	35659	4500	1800	7200	49639
11	T11	35659	12429	1800	7200	57568
12	T12	35659	12429	1800	7200	57568

Appendix. 6. Total cost of cultivation (₹/ha) incurred during the experiment in 2023.						
S. no	Treatment combination	Fixed cost (₹/ha)	Variable cost (₹/ha)			Cost of cultivation (₹/ha)
			Seed capsule	Hydrogel	Irrigation labour	
1	T1	35659	4500	0	6300	46459
2	T2	35659	4500	0	6300	46459
3	T3	35659	12429	0	6300	54388
4	T4	35659	12429	0	6300	54388
5	T5	35659	4500	900	4500	45559
6	T6	35659	4500	900	4500	45559
7	T7	35659	12429	900	4500	53488
8	T8	35659	12429	900	4500	53488
9	T9	35659	4500	1800	3600	45559
10	T10	35659	4500	1800	3600	45559
11	T11	35659	12429	1800	3600	53488
12	T12	35659	12429	1800	3600	53488



Appendix.7. Standard curve of BSA during protein content assessment.

ANOVA TABLES

Plant height 25 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.036	0.018				
Treatments	11	149.892	13.627	204.381	0.000		
Factor A	2	104.858	52.429	1,539.632	0.000	0.347	0.215
Error(a)	4	0.136	0.034				
Factor B	3	41.457	13.819	207.268	0.000	0.350	0.258
A X B	6	3.578	0.596	8.943	0.000	0.607	0.440
Error(b)	18	1.200	0.067				
Total	35	151.264					
	CV (a)	1.568		CV (b)	2.194		

Plant height 25 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.224	0.112				
Treatments	11	335.168	30.470	1,320.469	0.000		
Factor A	2	270.112	135.056	3,984.611	0.000	0.346	0.217
Error(a)	4	0.136	0.034				
Factor B	3	61.217	20.406	884.316	0.000	0.206	0.152
A X B	6	3.839	0.640	27.727	0.000	0.357	0.311
Error(b)	18	0.415	0.023				
Total	35	335.943					
	CV (a)	1.098		CV (b)	0.904		

Plant height 25 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.022	0.011				
Treatments	11	230.847	20.986	771.285	0.000		
Factor A	2	177.980	88.990	7,850.148	0.000	0.200	0.121
Error(a)	4	0.045	0.011				
Factor B	3	50.051	16.684	613.168	0.000	0.224	0.165
A X B	6	2.815	0.469	17.245	0.000	0.388	0.274
Error(b)	18	0.490	0.027				
Total	35	231.404					
	CV (a)	0.738		CV (b)	1.154		

Plant height 50 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.279	0.140				
Treatments	11	2,485.416	225.947	576.759	0.000		
Factor A	2	2,050.738	1,025.369	5,168.334	0.000	0.837	0.518
Error(a)	4	0.794	0.198				
Factor B	3	417.160	139.054	354.952	0.000	0.849	0.626
A X B	6	17.518	2.920	7.453	0.000	1.471	1.066
Error(b)	18	7.052	0.392				
Total	35	2,493.540					
	CV (a)	0.817		CV (b)	1.148		

Plant height 50 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	4.989	2.494				
Treatments	11	3,510.777	319.162	1,168.630	0.000		
Factor A	2	3,200.323	1,600.162	4,182.351	0.000	1.163	0.714
Error(a)	4	1.530	0.383				
Factor B	3	280.542	93.514	342.408	0.000	0.709	0.520
A X B	6	29.912	4.985	18.254	0.000	1.228	1.046
Error(b)	18	4.916	0.273				
Total	35	3,522.212					
	CV (a)	0.907		CV (b)	0.764		

Plant height 50 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	1.629	0.815				
Treatments	11	2,950.271	268.207	1,430.307	0.000		
Factor A	2	2,592.406	1,296.203	4,957.062	0.000	0.961	0.602
Error(a)	4	1.046	0.262				
Factor B	3	344.165	114.722	611.794	0.000	0.588	0.432
A X B	6	13.701	2.284	12.178	0.000	1.018	0.875
Error(b)	18	3.375	0.188				
Total	35	2,956.322					
	CV (a)	0.830		CV (b)	0.702		

Plant height 75 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	3.950	1.975				
Treatments	11	1,107.570	100.688	422.809	0.000		
Factor A	2	884.640	442.320	1,597.721	0.000	0.989	0.591
Error(a)	4	1.107	0.277				
Factor B	3	209.903	69.968	293.808	0.000	0.662	0.486
A X B	6	13.026	2.171	9.116	0.000	1.147	0.930
Error(b)	18	4.287	0.238				
Total	35	1,116.913					
	CV (a)	0.419		CV (b)	0.389		

Plant height 75 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	1.565	0.782				
Treatments	11	4,082.613	371.147	1,138.745	0.000		
Factor A	2	3,576.795	1,788.398	2,559.424	0.000	1.571	0.928
Error(a)	4	2.795	0.699				
Factor B	3	456.549	152.183	466.925	0.000	0.775	0.569
A X B	6	49.269	8.212	25.195	0.000	1.342	1.247
Error(b)	18	5.867	0.326				
Total	35	4,092.840					
	CV (a)	0.566		CV(b)	0.387		

Plant height 75 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	2.623	1.312				
Treatments	11	2,316.867	210.624	1,405.941	0.000		
Factor A	2	1,988.296	994.148	7,019.168	0.000	0.707	0.458
Error(a)	4	0.567	0.142				
Factor B	3	320.897	106.966	714.009	0.000	0.525	0.385
A X B	6	7.674	1.279	8.537	0.000	0.910	0.730
Error(b)	18	2.697	0.150				
Total	35	2,322.754					
	CV (a)	0.277		CV (b)	0.283		

Plant height 100 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	5.795	2.897				
Treatments	11	2,886.447	262.404	183.250	0.000		
Factor A	2	2,314.772	1,157.386	630.442	0.000	2.547	1.542
Error(a)	4	7.343	1.836				
Factor B	3	478.060	159.353	111.285	0.000	1.624	1.196
A X B	6	93.615	15.602	10.896	0.000	2.812	2.342
Error(b)	18	25.775	1.432				
Total	35	2,925.360					
	CV (a)	0.839		CV (b)	0.741		

Plant height 100 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	13.380	6.690				
Treatments	11	5,831.192	530.108	676.286	0.000		
Factor A	2	4,828.129	2,414.065	2,335.084	0.000	1.911	1.173
Error(a)	4	4.135	1.034				
Factor B	3	920.643	306.881	391.504	0.000	1.201	0.881
A X B	6	82.420	13.737	17.525	0.000	2.081	1.748
Error(b)	18	14.109	0.784				
Total	35	5,862.816					
	CV (a)	0.531		CV(b)	0.461		

Plant height 100 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	1.844	0.922				
Treatments	11	4,214.862	383.169	716.326	0.000		
Factor A	2	3,456.315	1,728.157	1,443.963	0.000	2.056	1.268
Error(a)	4	4.787	1.197				
Factor B	3	678.843	226.281	423.027	0.000	0.992	0.728
A X B	6	79.704	13.284	24.834	0.000	1.719	0.243
Error(b)	18	9.628	0.535				
Total	35	4,231.122					
	CV (a)	0.617		CV(b)	0.414		

Number of leaves 25 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.074	0.037				
Treatments	11	78.760	7.160	190.971	0.000		
Factor A	2	65.986	32.993	689.085	0.000	0.411	0.255
Error(a)	4	0.192	0.048				
Factor B	3	12.306	4.102	109.411	0.000	0.263	0.193
A X B	6	0.468	0.078	2.081	0.107	N/A	N/A
Error(b)	18	0.675	0.037				
Total	35	79.700					
	CV (a)	3.872			CV(b)	3.423	

Number of leaves 25 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.827	0.414				
Treatments	11	88.182	8.017	198.647	0.000		
Factor A	2	76.699	38.349	953.799	0.000	0.377	0.223
Error(a)	4	0.161	0.040				
Factor B	3	10.808	3.603	89.272	0.000	0.273	0.201
A X B	6	0.675	0.113	2.788	0.043	N/A	0.377
Error(b)	18	0.726	0.040				
Total	35	89.896					
	CV (a)	3.463			CV(b)	3.487	

Number of leaves 25 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.175	0.087				
Treatments	11	81.140	7.376	308.514	0.000		
Factor A	2	69.428	34.714	4,606.379	0.000	0.163	0.101
Error(a)	4	0.030	0.007				
Factor B	3	11.520	3.840	160.605	0.000	0.210	0.154
A X B	6	0.191	0.032	1.334	0.293	N/A	N/A
Error(b)	18	0.430	0.024				
Total	35	81.775					
	CV (a)	1.53			CV(b)	2.719	

Number of leaves 50 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.041	0.021				
Treatments	11	37.140	3.376	87.665	0.000		
Factor A	2	28.983	14.492	247.758	0.000	0.455	0.281
Error(a)	4	0.234	0.059				
Factor B	3	7.627	2.542	66.011	0.000	0.266	0.196
A X B	6	0.530	0.088	2.294	0.080	N/A	N/A
Error(b)	18	0.693	0.038				
Total	35	38.109					
	CV (a)	2.788			CV (b)	2.262	

Number of leaves 50 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	1.374	0.687				
Treatments	11	45.144	4.104	97.728	0.000		
Factor A	2	38.319	19.159	413.325	0.000	0.405	0.250
Error(a)	4	0.185	0.046				
Factor B	3	5.986	1.995	47.511	0.000	0.278	0.205
A X B	6	0.840	0.140	3.334	0.022	N/A	0.392
Error(b)	18	0.756	0.042				
Total	35	47.459					
	CV(a)	2.347			CV(b)	2.237	

Number of leaves 50 DAS (mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.466	0.233				
Treatments	11	40.544	3.686	169.123	0.000		
Factor A	2	33.399	16.699	539.513	0.000	0.331	0.204
Error(a)	4	0.124	0.031				
Factor B	3	6.742	2.247	103.124	0.000	0.200	0.147
A X B	6	0.403	0.067	3.078	0.030	N/A	0.298
Error(b)	18	0.392	0.022				
Total	35	41.526					
	CV(a)	1.998			CV(b)	1.65	

Number of leaves 75 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.129	0.065				
Treatments	11	23.848	2.168	46.796	0.000		
Factor A	2	17.168	8.584	119.517	0.000	0.504	0.313
Error(a)	4	0.287	0.072				
Factor B	3	5.777	1.926	41.568	0.000	0.292	0.215
A X B	6	0.902	0.150	3.245	0.024	N/A	0.444
Error(b)	18	0.834	0.046				
Total	35	25.098					
	CV(a)	1.79			CV(b)	1.438	

Number of leaves 75 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.019	0.009				
Treatments	11	26.132	2.376	71.432	0.000		
Factor A	2	19.029	9.515	295.677	0.000	0.337	0.209
Error(a)	4	0.129	0.032				
Factor B	3	6.353	2.118	63.671	0.000	0.247	0.182
A X B	6	0.750	0.125	3.759	0.013	N/A	0.340
Error(b)	18	0.599	0.033				
Total	35	26.878					
	CV (a)	1.17			CV(b)	1.189	

Number of leaves 75 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.018	0.009				
Treatments	11	24.894	2.263	126.946	0.000		
Factor A	2	18.076	9.038	198.825	0.000	0.401	0.249
Error(a)	4	0.182	0.045				
Factor B	3	6.037	2.012	112.877	0.000	0.181	0.133
A X B	6	0.780	0.130	7.296	0.000	0.314	0.316
Error(b)	18	0.321	0.018				
Total	35	25.415					
	CV(a)	1.408			CV(b)	0.884	

Number of leaves 100 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.301	0.150				
Treatments	11	26.169	2.379	40.086	0.000		
Factor A	2	18.414	9.207	350.302	0.000	0.305	0.189
Error(a)	4	0.105	0.026				
Factor B	3	6.681	2.227	37.526	0.000	0.331	0.243
A X B	6	1.074	0.179	3.016	0.032	N/A	0.408
Error(b)	18	1.068	0.059				
Total	35	27.644					
	CV(a)	1.233			CV(b)	1.853	

Number of leaves 100 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.019	0.009				
Treatments	11	24.377	2.216	53.006	0.000		
Factor A	2	18.389	9.195	142.260	0.000	0.478	0.297
Error(a)	4	0.259	0.065				
Factor B	3	5.211	1.737	41.546	0.000	0.277	0.204
A X B	6	0.777	0.130	3.096	0.029	N/A	0.422
Error(b)	18	0.752	0.042				
Total	35	25.407					
	CV(a)	1.812			CV(b)	1.458	

Number of leaves 100 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.095	0.048				
Treatments	11	25.140	2.285	75.404	0.000		
Factor A	2	18.420	9.210	240.838	0.000	0.368	0.230
Error(a)	4	0.153	0.038				
Factor B	3	5.910	1.970	64.994	0.000	0.236	0.174
A X B	6	0.810	0.135	4.457	0.006	0.409	0.344
Error(b)	18	0.546	0.030				
Total	35	25.934					
	CV(a)	1.427			CV(b)	1.281	

Stem girth 25 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.069	0.035				
Treatments	11	14.159	1.287	158.402	0.000		
Factor A	2	10.784	5.392	838.275	0.000	0.151	0.093
Error(a)	4	0.026	0.006				
Factor B	3	2.800	0.933	114.876	0.000	0.122	0.090
A X B	6	0.575	0.096	11.792	0.000	0.212	0.163
Error(b)	18	0.146	0.008				
Total	35	14.400					
	CV(a)	3.39			CV(b)	3.808	

Stem girth 25 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.009	0.004				
Treatments	11	6.001	0.545	551.670	0.000		
Factor A	2	5.243	2.622	2,899.419	0.000	0.057	0.035
Error(a)	4	0.004	0.001				
Factor B	3	0.655	0.218	220.699	0.000	0.043	0.031
A X B	6	0.103	0.017	17.374	0.000	0.074	0.058
Error(b)	18	0.018	0.001				
Total	35	6.031					
	CV(a)	0.956			CV(b)	0.988	

Stem girth 25 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.021	0.010				
Treatments	11	9.366	0.851	372.291	0.000		
Factor A	2	7.698	3.849	6,011.380	0.000	0.048	0.030
Error(a)	4	0.003	0.001				
Factor B	3	1.537	0.512	223.990	0.000	0.065	0.048
A X B	6	0.131	0.022	9.558	0.000	0.112	0.077
Error(b)	18	0.041	0.002				
Total	35	9.431					
	CV(a)	0.984			CV(b)	1.724	

Stem girth 50 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.000	0.000				
Treatments	11	9.829	0.894	166.077	0.000		
Factor A	2	8.249	4.125	654.823	0.000	0.149	0.092
Error(a)	4	0.025	0.006				
Factor B	3	1.254	0.418	77.693	0.000	0.100	0.073
A X B	6	0.326	0.054	10.110	0.000	0.172	0.142
Error(b)	18	0.097	0.005				
Total	35	9.952					
	CV(a)	1.599			CV(b)	1.478	

Stem girth 50 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.043	0.021				
Treatments	11	26.093	2.372	583.561	0.000		
Factor A	2	23.081	11.540	2,218.111	0.000	0.136	0.083
Error(a)	4	0.021	0.005				
Factor B	3	2.838	0.946	232.698	0.000	0.087	0.064
A X B	6	0.174	0.029	7.153	0.001	0.150	0.126
Error(b)	18	0.073	0.004				
Total	35	26.230					
	CV(a)	1.281		CV(b)	1.144		

Stem girth 50 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.011	0.006				
Treatments	11	16.628	1.512	992.432	0.000		
Factor A	2	14.654	7.327	2,686.150	0.000	0.098	0.061
Error(a)	4	0.011	0.003				
Factor B	3	1.799	0.600	393.615	0.000	0.053	0.039
A X B	6	0.175	0.029	19.125	0.000	0.092	0.083
Error(b)	18	0.027	0.002				
Total	35	16.678					
	CV(a)	1.026		CV(b)	0.749		

Stem girth 75 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.006	0.003				
Treatments	11	12.827	1.166	224.963	0.000		
Factor A	2	10.446	5.223	471.112	0.000	0.198	0.121
Error(a)	4	0.044	0.011				
Factor B	3	2.121	0.707	136.385	0.000	0.098	0.072
A X B	6	0.260	0.043	8.368	0.000	0.169	0.161
Error(b)	18	0.093	0.005				
Total	35	12.970					
	CV(a)	1.463		CV(b)	1		

Stem girth 75 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.012	0.006				
Treatments	11	16.543	1.504	527.500	0.000		
Factor A	2	14.464	7.232	1,007.585	0.000	0.159	0.099
Error(a)	4	0.029	0.007				
Factor B	3	1.976	0.658	230.975	0.000	0.072	0.053
A X B	6	0.103	0.017	5.997	0.001	0.125	0.125
Error(b)	18	0.051	0.003				
Total	35	16.635					
	CV(a)	1.092		CV(b)	0.685		

Stem girth 75 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.005	0.002				
Treatments	11	14.455	1.314	605.967	0.000		
Factor A	2	12.374	6.187	3,820.535	0.000	0.076	0.044
Error(a)	4	0.006	0.002				
Factor B	3	2.037	0.679	313.172	0.000	0.063	0.046
A X B	6	0.043	0.007	3.298	0.023	N/A	0.082
Error(b)	18	0.039	0.002				
Total	35	14.505					
	CV(a)	0.53		CV(b) : 0.62			

Stem girth 100 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.031	0.016				
Treatments	11	22.717	2.065	214.898	0.000		
Factor A	2	19.658	9.829	1,200.673	0.000	0.170	0.107
Error(a)	4	0.033	0.008				
Factor B	3	2.566	0.855	88.990	0.000	0.133	0.098
A X B	6	0.494	0.082	8.566	0.000	0.230	0.180
Error(b)	18	0.173	0.010				
Total	35	22.954					
			CV(a): 1.069	CV(b) : 1.156			

Stem girth 100 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.036	0.018				
Treatments	11	19.451	1.768	259.331	0.000		
Factor A	2	16.948	8.474	825.510	0.000	0.190	0.119
Error(a)	4	0.041	0.010				
Factor B	3	2.236	0.745	109.318	0.000	0.112	0.082
A X B	6	0.266	0.044	6.512	0.001	0.194	0.170
Error(b)	18	0.123	0.007				
Total	35	19.651					
			CV(a): 1.097	CV(b) : 0.879			

Stem girth 100 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.019	0.009				
Treatments	11	21.050	1.914	329.629	0.000		
Factor A	2	18.312	9.156	1,607.475	0.000	0.142	0.089
Error(a)	4	0.023	0.006				
Factor B	3	2.379	0.793	136.587	0.000	0.103	0.076
A X B	6	0.360	0.060	10.328	0.000	0.179	0.143
Error(b)	18	0.104	0.006				
Total	35	21.197					
			CV(a): 0.843	CV(b) : 0.847			

Stem diameter 25 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.007	0.004				
Treatments	11	1.442	0.131	160.909	0.000		
Factor A	2	1.101	0.550	980.678	0.000	0.045	0.030
Error(a)	4	0.002	0.001				
Factor B	3	0.282	0.094	115.482	0.000	0.039	0.029
A X B	6	0.059	0.010	12.149	0.000	0.067	0.052
Error(b)	18	0.015	0.001				
Total	35	1.466					
		CV(a): 3.39		CV(b) : 3.808			

Stem diameter 25 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.001	0.001				
Treatments	11	0.606	0.055	661.488	0.000		
Factor A	2	0.531	0.266	2,694.113	0.000	0.019	0.011
Error(a)	4	0.000	0.000				
Factor B	3	0.065	0.022	259.322	0.000	0.012	0.010
A X B	6	0.010	0.002	20.389	0.000	0.021	0.018
Error(b)	18	0.002	0.000				
Total	35	0.609					
		CV(a): 0.956		CV(b) : 0.988			

Stem diameter 25 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Source of Variation	D.F.	Sum of Square	Mean Squares	F-value	p-value	CD (1%)	CD (5%)
Replication	2	0.001	0.001				
Treatments	11	0.951	0.086	350.920	0.000		
Factor A	2	0.785	0.393	4,958.000	0.000	0.017	0.010
Error(a)	4	0.000	0.000				
Factor B	3	0.153	0.051	206.737	0.000	0.021	0.015
A X B	6	0.013	0.002	8.771	0.000	0.037	0.025
Error(b)	18	0.004	0.000				
		CV(a): 0.984		CV(b) : 1.724			

Stem diameter 50 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.000	0.000				
Treatments	11	0.995	0.090	178.877	0.000		
Factor A	2	0.836	0.418	750.439	0.000	0.044	0.029
Error(a)	4	0.002	0.001				
Factor B	3	0.125	0.042	82.652	0.000	0.031	0.023
A X B	6	0.034	0.006	11.042	0.000	0.053	0.045
Error(b)	18	0.009	0.001				
Total	35	1.006					
		CV(a): 1.599		CV(b) : 1.478			

Stem diameter 50 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.004	0.002				
Treatments	11	2.678	0.243	614.270	0.000		
Factor A	2	2.367	1.184	2,455.908	0.000	0.041	0.027
Error(a)	4	0.002	0.001				
Factor B	3	0.292	0.098	246.007	0.000	0.027	0.020
A X B	6	0.018	0.003	7.598	0.000	0.047	0.040
Error(b)	18	0.007	0.000				
Total	35	2.691					
		CV(a): 1.281		CV(b) : 1.144			

Stem diameter 50 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.002	0.001				
Treatments	11	1.672	0.152	800.593	0.000		
Factor A	2	1.469	0.735	2,204.175	0.000	0.034	0.020
Error(a)	4	0.001	0.000				
Factor B	3	0.184	0.061	323.176	0.000	0.019	0.013
A X B	6	0.018	0.003	15.917	0.000	0.032	0.027
Error(b)	18	0.003	0.000				
Total	35	1.678					
		CV(a): 1.026		CV(b) : 0.749			

Stem diameter 75 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.001	0.000				
Treatments	11	1.304	0.119	239.394	0.000		
Factor A	2	1.065	0.532	442.097	0.000	0.065	0.039
Error(a)	4	0.005	0.001				
Factor B	3	0.213	0.071	143.512	0.000	0.030	0.023
A X B	6	0.026	0.004	8.910	0.000	0.052	0.052
Error(b)	18	0.009	0.001				
Total	35	1.319					
		CV(a): 1.463		CV(b) : 1			

Stem diameter 75 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.001	0.001				
Treatments	11	1.681	0.153	554.002	0.000		
Factor A	2	1.468	0.734	1,050.541	0.000	0.050	0.031
Error(a)	4	0.003	0.001				
Factor B	3	0.203	0.068	245.621	0.000	0.023	0.017
A X B	6	0.010	0.002	6.245	0.001	0.039	0.040
Error(b)	18	0.005	0.000				
Total	35	1.691					
		CV(a): 1.092		CV(b) : 0.685			

Stem diameter 75 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.001	0.000				
Treatments	11	1.469	0.134	574.604	0.000		
Factor A	2	1.260	0.630	3,171.455	0.000	0.026	0.015
Error(a)	4	0.001	0.000				
Factor B	3	0.205	0.068	294.259	0.000	0.021	0.015
A X B	6	0.004	0.001	2.888	0.038	N/A	0.026
Error(b)	18	0.004	0.000				
Total	35	1.475					
		CV(a): 0.53		CV(b) : 0.622"			

Stem diameter 100 DAS (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.003	0.002				
Treatments	11	2.302	0.209	197.545	0.000		
Factor A	2	1.991	0.995	1,058.573	0.000	0.058	0.034
Error(a)	4	0.004	0.001				
Factor B	3	0.259	0.086	81.359	0.000	0.044	0.031
A X B	6	0.052	0.009	8.263	0.000	0.076	0.057
Error(b)	18	0.019	0.001				
Total	35	2.328					
		CV(a): 1.069		CV(b) : 1.156			

Stem diameter 100 DAS (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.004	0.002				
Treatments	11	1.964	0.178	246.223	0.000		
Factor A	2	1.709	0.855	769.143	0.000	0.063	0.038
Error(a)	4	0.004	0.001				
Factor B	3	0.227	0.075	104.198	0.000	0.037	0.027
A X B	6	0.028	0.005	6.390	0.001	0.063	0.046
Error(b)	18	0.013	0.001				
Total	35	1.985					
		CV(a): 1.097		CV(b) : 0.879			

Stem diameter 100 DAS (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.002	0.001				
Treatments	11	2.144	0.195	342.354	0.000		
Factor A	2	1.870	0.935	1,602.957	0.000	0.045	0.028
Error(a)	4	0.002	0.001				
Factor B	3	0.239	0.080	139.720	0.000	0.032	0.024
A X B	6	0.036	0.006	10.437	0.000	0.056	0.045
Error(b)	18	0.010	0.001				
Total	35	2.159					
		CV(a): 0.843		CV(b) : 0.847			

Number of cobs /plant (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.226	0.113				
Treatments	11	5.063	0.460	6.056	0.000		
Factor A	2	4.067	2.034	14.689	0.014	N/A	0.433
Error(a)	4	0.554	0.138				
Factor B	3	0.976	0.325	4.280	0.019	N/A	0.275
A X B	6	0.020	0.003	0.044	1.000	N/A	N/A
Error(b)	18	1.368	0.076				
Total	35	7.211					
		CV(a): 22.206	CV(b) : 16.454				

Number of cobs/plant (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.006	0.003				
Treatments	11	5.367	0.488	19.880	0.000		
Factor A	2	4.174	2.087	120.400	0.000	0.247	0.153
Error(a)	4	0.069	0.017				
Factor B	3	1.067	0.356	14.497	0.000	0.213	0.156
A X B	6	0.126	0.021	0.852	0.547	N/A	N/A
Error(b)	18	0.442	0.025				
Total	35	5.884					
		CV(a): 7.856	CV(b) : 9.348				

Number of cobs/plant (Mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.057	0.028				
Treatments	11	5.169	0.470	38.131	0.000		
Factor A	2	4.094	2.047	75.528	0.001	0.309	0.194
Error(a)	4	0.108	0.027				
Factor B	3	1.019	0.340	27.552	0.000	0.151	0.111
A X B	6	0.056	0.009	0.763	0.608	N/A	N/A
Error(b)	18	0.222	0.012				
Total	35	5.556					
		CV(a): 9.949	CV(b) : 6.633				

Length of cob (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	2.643	1.322				
Treatments	11	90.814	8.256	9.308	0.000		
Factor A	2	76.027	38.013	37.762	0.003	1.886	1.137
Error(a)	4	4.027	1.007				
Factor B	3	10.998	3.666	4.133	0.022	N/A	0.940
A X B	6	3.789	0.631	0.712	0.645	N/A	N/A
Error(b)	18	15.965	0.887				
Total	35	113.448					
		CV(a): 5.771	CV(b) : 5.417				

Length of cob (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	3.064	1.532				
Treatments	11	88.883	8.080	7.419	0.000		
Factor A	2	74.474	37.237	21.366	0.007	2.481	1.496
Error(a)	4	6.971	1.743				
Factor B	3	11.452	3.817	3.505	0.037	N/A	1.034
A X B	6	2.957	0.493	0.453	0.834	N/A	N/A
Error(b)	18	19.603	1.089				
Total	35	118.522					
		CV(a): 7.246	CV(b) : 5.728				

Length of cob (mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	2.818	1.409				
Treatments	11	89.754	8.159	8.330	0.000		
Factor A	2	75.242	37.621	28.016	0.004	2.178	1.313
Error(a)	4	5.371	1.343				
Factor B	3	11.205	3.735	3.813	0.028	N/A	0.980
A X B	6	3.307	0.551	0.563	0.754	N/A	N/A
Error(b)	18	17.632	0.980				
Total	35	115.577					
		CV(a): 6.507	CV(b) : 5.56				

Cob girth (2022)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (d5%)**
Replication	2	2.972	1.486				
Treatments	11	51.463	4.678	7.145	0.000		
Factor A	2	42.234	21.117	26.925	0.005	1.665	1.004
Error(a)	4	3.137	0.784				
Factor B	3	8.239	2.746	4.194	0.020	N/A	0.801
A X B	6	0.990	0.165	0.252	0.952	N/A	N/A
Error(b)	18	11.785	0.655				
Total	35	69.358					
		CV(a): 6.378	CV(b) : 5.828				

Cob girth (2023)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	3.117	1.558				
Treatments	11	52.749	4.795	5.496	0.001		
Factor A	2	42.953	21.477	19.333	0.009	1.981	1.195
Error(a)	4	4.444	1.111				
Factor B	3	8.989	2.996	3.434	0.039	N/A	0.925
A X B	6	0.807	0.135	0.154	0.986	N/A	N/A
Error(b)	18	15.705	0.873				
Total	35	76.015					
		CV(a): 7.313	CV(b) : 6.49				

Cob girth (mean)							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	3.027	1.514				
Treatments	11	52.117	4.738	6.250	0.000		
Factor A	2	42.638	21.319	22.808	0.006	1.817	1.096
Error(a)	4	3.739	0.935				
Factor B	3	8.617	2.872	3.789	0.029	N/A	0.862
A X B	6	0.861	0.144	0.189	0.976	N/A	N/A
Error(b)	18	13.645	0.758				
Total	35	72.528					
		CV(a): 6.847	CV(b) : 6.151				

Weight of cob with husk 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	501.480	250.740				
Treatments	11	9,262.901	842.082	28.448	0.000		
Factor A	2	7,852.358	3,926.179	88.140	0.000	12.545	7.765
Error(a)	4	178.178	44.545				
Factor B	3	1,323.608	441.202	14.905	0.000	7.383	5.388
A X B	6	86.936	14.489	0.489	0.808	N/A	N/A
Error(b)	18	532.820	29.601				
Total	35	10,475.379					
		CV(a): 3.578	CV(b) : 2.917				

Weight of cob with husk 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	1,108.777	554.389				
Treatments	11	10,322.992	938.454	44.421	0.000		
Factor A	2	7,836.585	3,918.292	62.892	0.001	14.836	9.247
Error(a)	4	249.208	62.302				
Factor B	3	2,110.453	703.484	33.299	0.000	6.237	4.552
A X B	6	375.954	62.659	2.966	0.034	N/A	11.385
Error(b)	18	380.276	21.126				
Total	35	12,061.252					
		CV(a): 3.869	CV(b) : 2.253				

Weight of cob with husk mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	774.810	387.405				
Treatments	11	9,667.306	878.846	57.938	0.000		
Factor A	2	7,808.397	3,904.198	103.798	0.000	11.528	7.052
Error(a)	4	150.453	37.613				
Factor B	3	1,684.912	561.637	37.026	0.000	5.285	3.857
A X B	6	173.998	29.000	1.912	0.134	N/A	N/A
Error(b)	18	273.039	15.169				
Total	35	10,865.608					
		CV(a): 3.141	CV(b) : 1.995				

Weight of cob without husk 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	467.031	233.515				
Treatments	11	10,517.732	956.158	38.344	0.000		
Factor A	2	8,129.688	4,064.844	168.522	0.000	9.231	5.667
Error(a)	4	96.483	24.121				
Factor B	3	2,235.266	745.089	29.879	0.000	6.776	4.946
A X B	6	152.778	25.463	1.021	0.443	N/A	N/A
Error(b)	18	448.858	24.936				
Total	35	11,530.103					
		CV(a): 3.428	CV(b) : 3.486				

Weight of cob without husk 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	1,570.234	785.117				
Treatments	11	9,685.865	880.533	34.193	0.000		
Factor A	2	7,096.573	3,548.286	53.530	0.001	15.303	9.528
Error(a)	4	265.143	66.286				
Factor B	3	2,176.607	725.536	28.174	0.000	6.886	5.026
A X B	6	412.685	68.781	2.671	0.049	N/A	11.705
Error(b)	18	463.527	25.752				
Total	35	11,984.769					
		CV(a): 5.311	CV(b) : 3.311				

Weight of cob without husk Mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	936.382	468.191				
Treatments	11	10,014.058	910.369	55.110	0.000		
Factor A	2	7,588.258	3,794.129	168.114	0.000	8.929	5.485
Error(a)	4	90.275	22.569				
Factor B	3	2,194.465	731.488	44.282	0.000	5.515	4.025
A X B	6	231.335	38.556	2.334	0.076	N/A	N/A
Error(b)	18	297.342	16.519				
Total	35	11,338.057					
		CV(a): 3.205	CV(b) : 2.741				

Number of rows per cob 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.953	0.476				
Treatments	11	40.246	3.659	3.511	0.009		
Factor A	2	26.692	13.346	8.763	0.035	N/A	1.399
Error(a)	4	6.092	1.523				
Factor B	3	11.846	3.949	3.789	0.029	N/A	1.011
A X B	6	1.709	0.285	0.273	0.942	N/A	N/A
Error(b)	18	18.757	1.042				
Total	35	66.047					
		CV(a): 10.735	CV(b) : 8.88				

Number of rows per cob 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	1.048	0.524				
Treatments	11	42.357	3.851	4.096	0.004		
Factor A	2	31.187	15.593	7.961	0.040	N/A	1.586
Error(a)	4	7.834	1.959				
Factor B	3	10.065	3.355	3.568	0.035	N/A	0.968
A X B	6	1.106	0.184	0.196	0.974	N/A	N/A
Error(b)	18	16.923	0.940				
Total	35	68.163					
		CV(a): 11.548	CV(b) : 8.001				

Number of rows per cob Mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.992	0.496				
Treatments	11	40.938	3.722	3.802	0.006		
Factor A	2	28.861	14.430	8.367	0.037	N/A	1.489
Error(a)	4	6.899	1.725				
Factor B	3	10.838	3.613	3.691	0.031	N/A	0.987
A X B	6	1.239	0.207	0.211	0.969	N/A	N/A
Error(b)	18	17.620	0.979				
Total	35	66.448					
		CV(a): 11.12	CV(b) : 8.379				

Number of grains per row of cob 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	9.013	4.506				
Treatments	11	47.825	4.348	5.192	0.001		
Factor A	2	36.940	18.470	6.994	0.049	N/A	1.842
Error(a)	4	10.563	2.641				
Factor B	3	10.458	3.486	4.163	0.021	N/A	0.913
A X B	6	0.427	0.071	0.085	0.997	N/A	N/A
Error(b)	18	15.073	0.837				
Total	35	82.474					
		CV(a): 5.549	CV(b) : 3.125				

Number of grains per row of cob 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	6.419	3.209				
Treatments	11	50.591	4.599	6.701	0.000		
Factor A	2	36.719	18.360	7.883	0.041	N/A	1.730
Error(a)	4	9.316	2.329				
Factor B	3	13.198	4.399	6.410	0.004	1.124	0.827
A X B	6	0.673	0.112	0.163	0.983	N/A	N/A
Error(b)	18	12.353	0.686				
Total	35	78.679					
		CV(a): 4.817	CV(b) : 2.615				

Number of grains per row of cob Mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	7.661	3.831				
Treatments	11	48.827	4.439	6.088	0.000		
Factor A	2	36.780	18.390	7.466	0.045	N/A	1.779
Error(a)	4	9.852	2.463				
Factor B	3	11.665	3.888	5.333	0.008	1.159	0.853
A X B	6	0.383	0.064	0.087	0.997	N/A	N/A
Error(b)	18	13.124	0.729				
Total	35	79.465					
		CV(a): 5.157	CV(b) : 2.803				

Number of grains per cob 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	1,020.214	510.107				
Treatments	11	70,220.285	6,383.662	5.967	0.000		
Factor A	2	49,338.747	24,669.374	41.853	0.002	45.634	28.219
Error(a)	4	2,357.740	589.435				
Factor B	3	19,149.734	6,383.245	5.967	0.005	44.380	32.593
A X B	6	1,731.804	288.634	0.270	0.944	N/A	N/A
Error(b)	18	19,255.484	1,069.749				
Total	35	92,853.724					
		CV(a): 7.191	CV(b) : 9.687				

Number of grains per cob 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	708.631	354.315				
Treatments	11	85,217.524	7,747.048	6.750	0.000		
Factor A	2	62,784.562	31,392.281	27.899	0.004	63.050	39.022
Error(a)	4	4,500.845	1,125.211				
Factor B	3	20,934.264	6,978.088	6.080	0.005	45.969	33.552
A X B	6	1,498.698	249.783	0.218	0.966	N/A	N/A
Error(b)	18	20,658.759	1,147.709				
Total	35	111,085.758					
		CV(a): 8.712	CV(b) : 8.799				

Number of grains per cob Mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	841.209	420.604				
Treatments	11	77,146.487	7,013.317	6.399	0.000		
Factor A	2	55,800.296	27,900.148	33.858	0.003	53.956	33.438
Error(a)	4	3,296.131	824.033				
Factor B	3	19,985.259	6,661.753	6.078	0.005	44.923	32.789
A X B	6	1,360.932	226.822	0.207	0.970	N/A	N/A
Error(b)	18	19,729.333	1,096.074				
Total	35	101,013.159					
CV(a): 7.944			CV(b) : 9.162				

Seed index 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	1.501	0.750				
Treatments	11	10.892	0.990	3.439	0.010		
Factor A	2	7.627	3.813	11.204	0.023	N/A	0.719
Error(a)	4	1.361	0.340				
Factor B	3	2.854	0.951	3.304	0.044	N/A	0.550
A X B	6	0.411	0.069	0.238	0.958	N/A	N/A
Error(b)	18	5.183	0.288				
Total	35	18.938					
		CV(a): 1.989	CV(b) : 1.769				

Seed index 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	1.374	0.687				
Treatments	11	11.147	1.013	3.375	0.011		
Factor A	2	7.809	3.905	10.792	0.024	N/A	0.699
Error(a)	4	1.447	0.362				
Factor B	3	2.948	0.983	3.273	0.045	N/A	0.547
A X B	6	0.390	0.065	0.217	0.967	N/A	N/A
Error(b)	18	5.404	0.300				
Total	35	19.372					
		CV(a): 1.906	CV(b) : 1.736				

Seed index Mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	1.404	0.702				
Treatments	11	10.940	0.995	3.305	0.012		
Factor A	2	7.551	3.776	10.131	0.027	N/A	0.707
Error(a)	4	1.491	0.373				
Factor B	3	3.001	1.000	3.324	0.043	N/A	0.547
A X B	6	0.388	0.065	0.215	0.967	N/A	N/A
Error(b)	18	5.417	0.301				
Total	35	19.253					
		CV(a): 1.946	CV(b) : 1.75				

Shelling percentage with husk 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	20.131	10.065				
Treatments	11	517.042	47.004	1.523	0.207		
Factor A	2	239.305	119.652	6.500	0.055	N/A	N/A
Error(a)	4	73.632	18.408				
Factor B	3	237.576	79.192	2.566	0.087	N/A	N/A
A X B	6	40.161	6.694	0.217	0.966	N/A	N/A
Error(b)	18	555.480	30.860				
Total	35	1,166.285					
		CV(a): 7.63	CV(b) : 9.88				

Shelling percentage with husk 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	50.309	25.155				
Treatments	11	475.045	43.186	1.352	0.275		
Factor A	2	324.586	162.293	3.228	0.146	N/A	N/A
Error(a)	4	201.089	50.272				
Factor B	3	143.822	47.941	1.501	0.248	N/A	N/A
A X B	6	6.637	1.106	0.035	1.000	N/A	N/A
Error(b)	18	575.096	31.950				
Total	35	1,301.539					
		CV(a): 11.92	CV(b) : 9.502				

Shelling percentage with husk Mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	28.591	14.295				
Treatments	11	475.638	43.240	1.439	0.238		
Factor A	2	280.007	140.004	4.430	0.097	N/A	N/A
Error(a)	4	126.407	31.602				
Factor B	3	187.167	62.389	2.076	0.139	N/A	N/A
A X B	6	8.464	1.411	0.047	0.999	N/A	N/A
Error(b)	18	540.932	30.052				
Total	35	1,171.568					
		CV(a): 9.714	CV(b) : 9.477				

Shelling percentage without husk 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	55.500	27.750				
Treatments	11	223.964	20.360	0.315	0.972		
Factor A	2	77.214	38.607	0.930	0.466	N/A	N/A
Error(a)	4	166.096	41.524				
Factor B	3	108.730	36.243	0.561	0.648	N/A	N/A
A X B	6	38.020	6.337	0.098	0.996	N/A	N/A
Error(b)	18	1,162.957	64.609				
Total	35	1,608.517					
		CV(a): 8.777	CV(b) : 10.95				

Shelling percentage without husk 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	288.080	144.040				
Treatments	11	346.259	31.478	0.462	0.904		
Factor A	2	214.731	107.365	0.869	0.486	N/A	N/A
Error(a)	4	494.120	123.530				
Factor B	3	92.786	30.929	0.454	0.718	N/A	N/A
A X B	6	38.743	6.457	0.095	0.996	N/A	N/A
Error(b)	18	1,226.925	68.162				
Total	35	2,355.384					
		CV(a): 13.991	CV(b) : 10.396				

Shelling percentage without husk Mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	133.403	66.701				
Treatments	11	243.794	22.163	0.354	0.959		
Factor A	2	137.230	68.615	0.915	0.471	N/A	N/A
Error(a)	4	299.969	74.992				
Factor B	3	96.077	32.026	0.511	0.680	N/A	N/A
A X B	6	10.487	1.748	0.028	1.000	N/A	N/A
Error(b)	18	1,128.026	62.668				
Total	35	1,805.192					
		CV(a): 11.333	CV(b) : 10.361				

Grain yield 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.000	0.000				
Treatments	11	24.130	2.194	137.661	0.000		
Factor A	2	18.652	9.326	4,062.152	0.000	0.090	0.053
Error(a)	4	0.009	0.002				
Factor B	3	4.877	1.625	102.006	0.000	0.171	0.126
A X B	6	0.602	0.100	6.293	0.001	0.297	0.217
Error(b)	18	0.287	0.016				
Total	35	24.427					
		CV(a): 0.576		CV(b) : 1.56			

Grain yield 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.005	0.003				
Treatments	11	33.650	3.059	303.071	0.000		
Factor A	2	29.726	14.863	2,199.196	0.000	0.155	0.095
Error(a)	4	0.027	0.007				
Factor B	3	3.738	1.246	123.443	0.000	0.136	0.100
A X B	6	0.186	0.031	3.068	0.030	N/A	0.177
Error(b)	18	0.182	0.010				
Total	35	33.864					
		CV(a): 0.934		CV(b) : 1.141			

Grain yield mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.002	0.001				
Treatments	11	28.206	2.564	839.956	0.000		
Factor A	2	23.860	11.930	8,118.864	0.000	0.072	0.045
Error(a)	4	0.006	0.002				
Factor B	3	4.150	1.383	453.174	0.000	0.075	0.055
A X B	6	0.195	0.033	10.669	0.000	0.130	0.093
Error(b)	18	0.055	0.003				
Total	35	28.269					
		CV(a): 0.471	CV(b) : 0.668				

Stover yield 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.116	0.058				
Treatments	11	52.941	4.813	95.492	0.000		
Factor A	2	42.403	21.201	209.901	0.000	0.597	0.370
Error(a)	4	0.404	0.101				
Factor B	3	8.561	2.854	56.620	0.000	0.305	0.244
A X B	6	1.977	0.330	6.537	0.001	0.528	0.494
Error(b)	18	0.907	0.050				
Total	35	54.368					
		CV(a): 2.212		CV(b) : 1.562			

Stover yield 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.024	0.012				
Treatments	11	47.841	4.349	249.579	0.000		
Factor A	2	40.879	20.439	3,195.721	0.000	0.150	0.092
Error(a)	4	0.026	0.006				
Factor B	3	6.399	2.133	122.398	0.000	0.179	0.132
A X B	6	0.563	0.094	5.388	0.002	0.310	0.217
Error(b)	18	0.314	0.017				
Total	35	48.203					
		CV(a): 0.518		CV(b) : 0.855			

Stover yield mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.009	0.005				
Treatments	11	49.736	4.521	251.801	0.000		
Factor A	2	41.631	20.816	1,419.246	0.000	0.228	0.142
Error(a)	4	0.059	0.015				
Factor B	3	7.246	2.415	134.513	0.000	0.182	0.134
A X B	6	0.859	0.143	7.970	0.000	0.315	0.244
Error(b)	18	0.323	0.018				
Total	35	50.127					
		CV(a): 0.812	CV(b) : 0.907				

Biological yield 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.212	0.106				
Treatments	11	80.298	7.300	33.680	0.000		
Factor A	2	62.127	31.064	449.141	0.000	0.494	0.305
Error(a)	4	0.277	0.069				
Factor B	3	16.299	5.433	25.067	0.000	0.632	0.465
A X B	6	1.872	0.312	1.439	0.254	N/A	N/A
Error(b)	18	3.901	0.217				
Total	35	84.688					
		CV(a): 1.118	CV(b) : 1.98				

Biological yield 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.039	0.020				
Treatments	11	160.726	14.611	515.327	0.000		
Factor A	2	140.278	70.139	3,191.754	0.000	0.279	0.176
Error(a)	4	0.088	0.022				
Factor B	3	19.908	6.636	234.040	0.000	0.228	0.168
A X B	6	0.540	0.090	3.176	0.026	N/A	0.305
Error(b)	18	0.510	0.028				
Total	35	161.363					
		CV(a): 0.599	CV(b) : 0.681				

Biological yield Mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.103	0.052				
Treatments	11	115.325	10.484	163.716	0.000		
Factor A	2	97.170	48.585	2,406.860	0.000	0.267	0.164
Error(a)	4	0.081	0.020				
Factor B	3	17.608	5.869	91.654	0.000	0.343	0.253
A X B	6	0.546	0.091	1.421	0.260	N/A	N/A
Error(b)	18	1.153	0.064				
Total	35	116.661					
		CV(a): 0.592	CV(b) : 1.046				

Harvest index 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.323	0.161				
Treatments	11	73.137	6.649	13.291	0.000		
Factor A	2	43.398	21.699	177.130	0.000	0.658	0.491
Error(a)	4	0.490	0.122				
Factor B	3	22.541	7.514	15.020	0.000	0.960	0.877
A X B	6	7.199	1.200	2.398	0.070	N/A	N/A
Error(b)	18	9.004	0.500				
Total	35	82.954					
		CV(a): 1.23	CV(b) : 2.559				

Harvest index 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.063	0.032				
Treatments	11	29.901	2.718	25.914	0.000		
Factor A	2	25.554	12.777	418.535	0.000	0.328	0.204
Error(a)	4	0.122	0.030				
Factor B	3	1.803	0.601	5.730	0.006	0.439	0.323
A X B	6	2.544	0.424	4.042	0.010	0.761	0.523
Error(b)	18	1.888	0.105				
Total	35	31.974					
		CV(a): 0.496	CV(b) : 0.911				

Harvest index Mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.132	0.066				
Treatments	11	42.927	3.902	26.217	0.000		
Factor A	2	35.897	17.949	527.666	0.000	0.347	0.220
Error(a)	4	0.136	0.034				
Factor B	3	5.564	1.855	12.458	0.000	0.524	0.385
A X B	6	1.466	0.244	1.642	0.193	N/A	N/A
Error(b)	18	2.679	0.149				
Total	35	45.875					
		CV(a): 0.527	CV(b) : 1.106				

Available N in soil 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	264.957	132.479				
Treatments	11	892.984	81.180	1.162	0.375		
Factor A	2	672.462	336.231	3.825	0.118	N/A	N/A
Error(a)	4	351.649	87.912				
Factor B	3	214.084	71.361	1.022	0.406	N/A	N/A
A X B	6	6.438	1.073	0.015	1.000	N/A	N/A
Error(b)	18	1,257.385	69.855				
Total	35	2,766.976					
			CV(a): 3.192 , CV(b) : 5.008				

Available N in the soil 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	494.688	247.344				
Treatments	11	1,405.174	127.743	1.024	0.466		
Factor A	2	1,127.752	563.876	5.260	0.076	N/A	N/A
Error(a)	4	428.768	107.192				
Factor B	3	257.467	85.822	0.688	0.571	N/A	N/A
A X B	6	19.955	3.326	0.027	1.000	N/A	N/A
Error(b)	18	2,246.391	124.799				
Total	35	4,575.021					
			CV(a): 6.365 , CV(b) : 6.107				

Available N in the soil Mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	245.470	122.735				
Treatments	11	1,126.722	102.429	1.632	0.172		
Factor A	2	885.475	442.738	10.513	0.026	N/A	7.556
Error(a)	4	168.447	42.112				
Factor B	3	234.380	78.127	1.245	0.323	N/A	N/A
A X B	6	6.867	1.145	0.018	1.000	N/A	N/A
Error(b)	18	1,129.905	62.773				
Total	35	2,670.544					
			CV(a): 3.577 , CV(b) : 4.423				

Available P in the soil 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	43.514	21.757				
Treatments	11	37.136	3.376	0.653	0.762		
Factor A	2	30.961	15.480	3.755	0.121	N/A	N/A
Error(a)	4	16.489	4.122				
Factor B	3	5.444	1.815	0.351	0.789	N/A	N/A
A X B	6	0.731	0.122	0.024	1.000	N/A	N/A
Error(b)	18	92.998	5.167				
Total	35	190.138					
			CV(a): 6.663 , CV(b) : 12.498				

Available P in the soil 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	19.090	9.545				
Treatments	11	31.668	2.879	0.364	0.954		
Factor A	2	21.546	10.773	4.208	0.104	N/A	N/A
Error(a)	4	10.241	2.560				
Factor B	3	8.977	2.992	0.379	0.770	N/A	N/A
A X B	6	1.146	0.191	0.024	1.000	N/A	N/A
Error(b)	18	142.244	7.902				
Total	35	203.244					
			CV(a): 8.81 , CV(b) : 15.21				

Available P in the soil mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	7.398	3.699				
Treatments	11	33.722	3.066	0.794	0.644		
Factor A	2	25.872	12.936	21.402	0.007	1.461	0.904
Error(a)	4	2.418	0.604				
Factor B	3	7.035	2.345	0.608	0.619	N/A	N/A
A X B	6	0.814	0.136	0.035	1.000	N/A	N/A
Error(b)	18	69.483	3.860				
Total	35	113.020					
			CV(a): 4.453 , CV(b) : 10.711				

Available K in the soil 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	352.767	176.383				
Treatments	11	1,193.634	108.512	0.752	0.680		
Factor A	2	929.937	464.968	6.167	0.060	N/A	N/A
Error(a)	4	301.603	75.401				
Factor B	3	133.830	44.610	0.309	0.819	N/A	N/A
A X B	6	129.867	21.645	0.150	0.987	N/A	N/A
Error(b)	18	2,598.070	144.337				
Total	35	4,446.075					
			CV(a): 7.662 , CV(b) : 8.465				

Available K in the soil 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	300.365	150.183				
Treatments	11	569.167	51.742	0.540	0.851		
Factor A	2	485.210	242.605	1.486	0.329	N/A	N/A
Error(a)	4	653.179	163.295				
Factor B	3	68.522	22.841	0.238	0.868	N/A	N/A
A X B	6	15.436	2.573	0.027	1.000	N/A	N/A
Error(b)	18	1,725.209	95.845				
Total	35	3,247.921					
			CV(a): 11.405 , CV(b) : 6.053				

Available K in the soil Mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	34.426	17.213				
Treatments	11	816.211	74.201	0.945	0.523		
Factor A	2	676.711	338.356	4.056	0.109	N/A	N/A
Error(a)	4	333.695	83.424				
Factor B	3	94.821	31.607	0.403	0.753	N/A	N/A
A X B	6	44.679	7.447	0.095	0.996	N/A	N/A
Error(b)	18	1,412.837	78.491				
Total	35	2,597.170					
			CV(a): 8.228 , CV(b) : 5.836				

Grain Nitrogen Uptake 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	20.471	10.235				
Treatments	11	349.137	31.740	4.430	0.003		
Factor A	2	251.138	125.569	9.437	0.031	N/A	4.135
Error(a)	4	53.224	13.306				
Factor B	3	78.959	26.320	3.674	0.032	N/A	2.651
A X B	6	19.041	3.173	0.443	0.840	N/A	N/A
Error(b)	18	128.960	7.164				
Total	35	551.792					
		CV(a): 6.442	CV(b) : 4.727				

Stover nitrogen uptake 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	29.475	14.737				
Treatments	11	434.365	39.488	7.562	0.000		
Factor A	2	348.764	174.382	8.707	0.035	N/A	5.173
Error(a)	4	80.114	20.029				
Factor B	3	78.640	26.213	5.020	0.011	N/A	2.263
A X B	6	6.961	1.160	0.222	0.964	N/A	N/A
Error(b)	18	93.988	5.221				
Total	35	637.942					
		CV(a): 11.029	CV(b) : 5.631				

Total nitrogen uptake2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	99.065	49.532				
Treatments	11	1,527.081	138.826	15.984	0.000		
Factor A	2	1,191.713	595.856	97.749	0.000	4.641	2.799
Error(a)	4	24.383	6.096				
Factor B	3	309.824	103.275	11.890	0.000	3.999	2.919
A X B	6	25.545	4.258	0.490	0.807	N/A	N/A
Error(b)	18	156.340	8.685				
Total	35	1,806.869					
		CV(a): 2.54	CV(b) : 3.032				

Grain Nitrogen uptake 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	23.165	11.582				
Treatments	11	361.522	32.866	3.880	0.005		
Factor A	2	274.802	137.401	9.524	0.030	N/A	4.305
Error(a)	4	57.705	14.426				
Factor B	3	83.239	27.746	3.275	0.045	N/A	2.883
A X B	6	3.480	0.580	0.068	0.998	N/A	N/A
Error(b)	18	152.487	8.472				
Total	35	594.879					
		CV(a): 6.119	CV(b) : 4.689				

Stover Nitrogen uptake 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	35.794	17.897				
Treatments	11	438.559	39.869	9.304	0.000		
Factor A	2	343.430	171.715	7.590	0.043	N/A	5.391
Error(a)	4	90.497	22.624				
Factor B	3	89.208	29.736	6.940	0.003	2.809	2.050
A X B	6	5.920	0.987	0.230	0.961	N/A	N/A
Error(b)	18	77.130	4.285				
Total	35	641.980					
		CV(a): 9.886	CV(b) : 4.302				

Total nitrogen uptake 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	115.925	57.962				
Treatments	11	1,581.225	143.748	11.945	0.000		
Factor A	2	1,232.068	616.034	41.082	0.002	7.279	4.489
Error(a)	4	59.981	14.995				
Factor B	3	344.003	114.668	9.529	0.001	4.707	3.436
A X B	6	5.154	0.859	0.071	0.998	N/A	N/A
Error(b)	18	216.612	12.034				
Total	35	1,973.742					
		CV(a): 3.514	CV(b) : 3.148				

Grain nitrogen uptake mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	21.797	10.898				
Treatments	11	347.695	31.609	5.396	0.001		
Factor A	2	262.597	131.299	11.095	0.023	N/A	3.899
Error(a)	4	47.335	11.834				
Factor B	3	78.604	26.201	4.473	0.016	N/A	2.397
A X B	6	6.494	1.082	0.185	0.977	N/A	N/A
Error(b)	18	105.443	5.858				
Total	35	522.270					
		CV(a): 5.795	CV(b) : 4.079				

Stover nitrogen uptake mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	32.422	16.211				
Treatments	11	435.588	39.599	8.488	0.000		
Factor A	2	346.084	173.042	8.141	0.039	N/A	5.326
Error(a)	4	85.018	21.255				
Factor B	3	83.836	27.945	5.990	0.005	2.931	2.139
A X B	6	5.668	0.945	0.202	0.972	N/A	N/A
Error(b)	18	83.980	4.665				
Total	35	637.008					
		CV(a): 10.396	CV(b) : 4.871				

Total nitrogen uptake mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	107.247	53.623				
Treatments	11	1,546.658	140.605	17.420	0.000		
Factor A	2	1,211.696	605.848	75.157	0.001	5.337	3.218
Error(a)	4	32.245	8.061				
Factor B	3	324.237	108.079	13.390	0.000	3.855	2.814
A X B	6	10.724	1.787	0.221	0.965	N/A	N/A
Error(b)	18	145.284	8.071				
Total	35	1,831.433					
		CV(a): 2.738	CV(b) : 2.74				

Grain phosphorous 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	7.942	3.971				
Treatments	11	66.658	6.060	5.081	0.001		
Factor A	2	51.154	25.577	21.357	0.007	2.057	1.240
Error(a)	4	4.790	1.198				
Factor B	3	15.023	5.008	4.199	0.020	N/A	1.082
A X B	6	0.480	0.080	0.067	0.998	N/A	N/A
Error(b)	18	21.469	1.193				
Total	35	100.860					
		CV(a): 8.543	CV(b) : 8.526				

Stover phosphorous 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	2.559	1.280				
Treatments	11	78.048	7.095	6.987	0.000		
Factor A	2	61.578	30.789	11.968	0.021	N/A	1.818
Error(a)	4	10.291	2.573				
Factor B	3	15.022	5.007	4.931	0.011	N/A	0.998
A X B	6	1.448	0.241	0.238	0.958	N/A	N/A
Error(b)	18	18.279	1.016				
Total	35	109.176					
			CV(a): 14.433	CV(b) 9.068			

Total phosphorous 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	16.917	8.459				
Treatments	11	287.486	26.135	10.049	0.000		
Factor A	2	224.981	112.490	83.049	0.001	2.188	1.319
Error(a)	4	5.418	1.355				
Factor B	3	59.960	19.986	7.685	0.002	2.188	1.597
A X B	6	2.546	0.424	0.163	0.983	N/A	N/A
Error(b)	18	46.815	2.601				
Total	35	356.636					
			CV(a): 4.865 , CV(b) : 6.741				

Grain phosphorous 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	6.063	3.032				
Treatments	11	64.105	5.828	6.297	0.000		
Factor A	2	50.592	25.296	14.537	0.015	N/A	1.495
Error(a)	4	6.960	1.740				
Factor B	3	12.908	4.303	4.649	0.014	N/A	0.953
A X B	6	0.606	0.101	0.109	0.994	N/A	N/A
Error(b)	18	16.659	0.925				
Total	35	93.787					
		CV(a): 9.739	CV(b) : 7.103				

Stover phosphorous 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	2.730	1.365				
Treatments	11	80.312	7.301	6.366	0.000		
Factor A	2	63.819	31.910	11.738	0.021	N/A	1.869
Error(a)	4	10.874	2.718				
Factor B	3	15.055	5.019	4.376	0.018	N/A	1.061
A X B	6	1.438	0.240	0.209	0.969	N/A	N/A
Error(b)	18	20.644	1.147				
Total	35	114.560					
			CV(a): 14.113 , CV(b) : 9.17				

Total phosphorous 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	15.370	7.685				
Treatments	11	285.508	25.955	11.026	0.000		
Factor A	2	228.047	114.023	99.251	0.000	2.015	1.215
Error(a)	4	4.595	1.149				
Factor B	3	55.659	18.553	7.882	0.001	2.082	1.520
A X B	6	1.802	0.300	0.128	0.991	N/A	N/A
Error(b)	18	42.372	2.354				
Total	35	347.845					
			CV(a): 4.249 , CV(b) : 6.082				

Grain phosphrous mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	6.961	3.481				
Treatments	11	65.327	5.939	5.680	0.001		
Factor A	2	50.872	25.436	17.627	0.010	N/A	1.362
Error(a)	4	5.772	1.443				
Factor B	3	13.941	4.647	4.444	0.017	N/A	1.013
A X B	6	0.514	0.086	0.082	0.997	N/A	N/A
Error(b)	18	18.821	1.046				
Total	35	96.882					
		CV(a): 9.116	CV(b) : 7.76				

Stover phosphorous mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	2.641	1.320				
Treatments	11	79.158	7.196	6.671	0.000		
Factor A	2	62.692	31.346	11.854	0.021	N/A	1.843
Error(a)	4	10.578	2.644				
Factor B	3	15.035	5.012	4.646	0.014	N/A	1.029
A X B	6	1.431	0.238	0.221	0.965	N/A	N/A
Error(b)	18	19.418	1.079				
Total	35	111.794					
			CV(a): 14.267 , CV(b) : 9.113				

Total phosphorous Mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	16.124	8.062				
Treatments	11	286.440	26.040	10.578	0.000		
Factor A	2	226.511	113.255	91.726	0.000	2.089	1.259
Error(a)	4	4.939	1.235				
Factor B	3	57.781	19.260	7.824	0.002	2.129	1.554
A X B	6	2.148	0.358	0.145	0.988	N/A	N/A
Error(b)	18	44.312	2.462				
Total	35	351.815					
			CV(a): 4.522 , CV(b) : 6.385				

Grain potassium 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	8.945	4.473				
Treatments	11	73.779	6.707	5.318	0.001		
Factor A	2	56.298	28.149	20.920	0.008	2.180	1.315
Error(a)	4	5.382	1.346				
Factor B	3	17.033	5.678	4.502	0.016	N/A	1.112
A X B	6	0.448	0.075	0.059	0.999	N/A	N/A
Error(b)	18	22.701	1.261				
Total	35	110.807					
			CV(a): 6.699 , CV(b) : 6.485				

Stover potassium 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	30.942	15.471				
Treatments	11	455.894	41.445	9.226	0.000		
Factor A	2	371.278	185.639	7.740	0.042	N/A	5.651
Error(a)	4	95.934	23.983				
Factor B	3	75.747	25.249	5.621	0.007	2.876	2.099
A X B	6	8.869	1.478	0.329	0.913	N/A	N/A
Error(b)	18	80.861	4.492				
Total	35	663.632					
			CV(a): 6.27 , CV(b) : 2.714				

Total potassium 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	72.164	36.082				
Treatments	11	892.825	81.166	16.116	0.000		
Factor A	2	716.688	358.344	19.447	0.009	8.069	4.866
Error(a)	4	73.708	18.427				
Factor B	3	164.492	54.831	10.887	0.000	3.045	2.223
A X B	6	11.645	1.941	0.385	0.879	N/A	N/A
Error(b)	18	90.656	5.037				
Total	35	1,129.353					
			CV(a): 4.499 , CV(b) : 2.352				

Grain potassium 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	7.024	3.512				
Treatments	11	69.583	6.326	5.759	0.001		
Factor A	2	56.278	28.139	13.892	0.016	N/A	1.613
Error(a)	4	8.102	2.026				
Factor B	3	12.856	4.285	3.902	0.026	N/A	1.038
A X B	6	0.449	0.075	0.068	0.998	N/A	N/A
Error(b)	18	19.771	1.098				
Total	35	104.480					
			CV(a): 7.784 , CV(b) : 5.732				

Stover potassium 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	43.334	21.667				
Treatments	11	444.191	40.381	10.004	0.000		
Factor A	2	348.992	174.496	7.595	0.043	N/A	5.533
Error(a)	4	91.904	22.976				
Factor B	3	89.949	29.983	7.428	0.002	2.726	1.990
A X B	6	5.250	0.875	0.217	0.966	N/A	N/A
Error(b)	18	72.653	4.036				
Total	35	652.082					
			CV(a): 5.592 , CV(b) : 2.344				

Total potassium 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	84.427	42.213				
Treatments	11	861.870	78.352	20.006	0.000		
Factor A	2	684.841	342.421	18.780	0.009	8.026	4.840
Error(a)	4	72.933	18.233				
Factor B	3	170.643	56.881	14.524	0.000	2.685	1.960
A X B	6	6.386	1.064	0.272	0.943	N/A	N/A
Error(b)	18	70.495	3.916				
Total	35	1,089.725					
			CV(a): 4.106 , CV(b) : 1.903				

Grain potassium uptake mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	7.796	3.898				
Treatments	11	71.404	6.491	5.739	0.001		
Factor A	2	56.275	28.138	17.452	0.011	N/A	1.439
Error(a)	4	6.449	1.612				
Factor B	3	14.860	4.954	4.380	0.018	N/A	1.053
A X B	6	0.269	0.045	0.040	1.000	N/A	N/A
Error(b)	18	20.358	1.131				
Total	35	106.008					
			CV(a): 7.133 , CV(b) : 5.974				

Stover potassium uptake mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	36.588	18.294				
Treatments	11	448.780	40.798	9.828	0.000		
Factor A	2	359.992	179.996	7.674	0.043	N/A	5.590
Error(a)	4	93.824	23.456				
Factor B	3	82.571	27.524	6.631	0.003	2.765	2.018
A X B	6	6.218	1.036	0.250	0.953	N/A	N/A
Error(b)	18	74.719	4.151				
Total	35	653.911					
			CV(a): 5.913 , CV(b) : 2.487				

Total potassium uptake mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	78.157	39.079				
Treatments	11	875.610	79.601	18.507	0.000		
Factor A	2	700.659	350.330	19.235	0.009	8.022	4.837
Error(a)	4	72.853	18.213				
Factor B	3	167.476	55.825	12.979	0.000	2.814	2.054
A X B	6	7.475	1.246	0.290	0.934	N/A	N/A
Error(b)	18	77.418	4.301				
Total	35	1,104.039					
			CV(a): 4.28 , CV(b) : 2.08				

Grain protein content 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.462	0.231				
Treatments	11	39.141	3.558	21.708	0.000		
Factor A	2	33.711	16.855	219.735	0.000	0.521	0.323
Error(a)	4	0.307	0.077				
Factor B	3	4.066	1.355	8.268	0.001	0.549	0.404
A X B	6	1.364	0.227	1.387	0.273	N/A	N/A
Error(b)	18	2.950	0.164				
Total	35	42.860					
			CV(a): 3.029 , CV(b) : 4.427				

Grain protein content 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.462	0.231				
Treatments	11	39.141	3.558	22.421	0.000		
Factor A	2	29.129	14.565	145.391	0.000	0.595	0.369
Error(a)	4	0.401	0.100				
Factor B	3	8.271	2.757	17.373	0.000	0.541	0.398
A X B	6	1.740	0.290	1.828	0.150	N/A	N/A
Error(b)	18	2.857	0.159				
Total	35	42.860					
			CV(a): 2.84 , CV(b) : 3.574				

Grain protein content mean							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.462	0.231				
Treatments	11	38.560	3.505	27.552	0.000		
Factor A	2	31.291	15.646	183.386	0.000	0.549	0.340
Error(a)	4	0.341	0.085				
Factor B	3	6.163	2.054	16.148	0.000	0.484	0.356
A X B	6	1.105	0.184	1.448	0.251	N/A	N/A
Error(b)	18	2.290	0.127				
Total	35	41.653					
			CV(a): 2.879 , CV(b) : 3.516				

Grain appearance score 2022							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	1.199	0.599				
Treatments	11	9.038	0.822	39.817	0.000		
Factor A	2	7.799	3.900	110.018	0.000	0.354	0.219
Error(a)	4	0.142	0.035				
Factor B	3	1.196	0.399	19.328	0.000	0.195	0.143
A X B	6	0.043	0.007	0.345	0.903	N/A	N/A
Error(b)	18	0.371	0.021				
Total	35	10.750					
			CV(a): 10.073 , CV(b) : 7.669				

Grain appearance score 2023							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.130	0.065				
Treatments	11	8.222	0.748	19.636	0.000		
Factor A	2	6.907	3.454	186.500	0.000	0.256	0.158
Error(a)	4	0.074	0.018				
Factor B	3	1.210	0.403	10.595	0.000	0.265	0.195
A X B	6	0.105	0.018	0.459	0.829	N/A	N/A
Error(b)	18	0.685	0.038				
Total	35	9.111					
			CV(a): 6.124 , CV(b) : 8.78				

Grain appearance score							
Source of Variation	**D.F.**	**Sum of Square**	**Mean Squares**	**F-value**	**p-value**	**CD (1%)**	**CD (5%)**
Replication	2	0.140	0.070				
Treatments	11	8.534	0.776	65.573	0.000		
Factor A	2	7.289	3.644	410.696	0.000	0.177	0.110
Error(a)	4	0.035	0.009				
Factor B	3	1.201	0.400	33.826	0.000	0.148	0.109
A X B	6	0.045	0.007	0.630	0.704	N/A	N/A
Error(b)	18	0.213	0.012				
Total	35	8.923					
				CV(a): 4.603 , CV(b) : 5.316			