EFFECT OF POTASSIUM AND COPPER ON YIELD AND QUALITY OF POTATO (*Solanum Tuberosum*L.) IN A TYPIC USTORTHENT SOIL IN SUB - MOUNTAIN AREA OF PUNJAB

A Thesis

Submitted in partial fulfillment of the

requirements for the award of the degree of

DOCTOR OF PHILOSOPHY

in

(Agronomy)

By

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Supervised By

Dr. Raj Kumar

Transforming Education Transforming India

LOVELY PROFESSIONAL UNIVERSITY

PUNJAB

2022

Department of Agronomy
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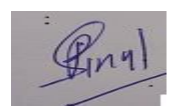
Punjab

DECLARATION

I hereby declare that the research work presented in the thesis entitled, "**Effect of potassium and copper on yield and quality of potato (*Solanum tuberosum* L.) in a Typic Ustorthent soil in sub - mountain area of Punjab**" is my own original. The work has been carried out by me in School of Agriculture, Lovely Professional University, Phagwara, Punjab (India) under the guidance of Dr. Raj Kumar, Professor (Department of Soil Science and Agriculture Chemistry) of School of Agriculture, Lovely Professional University, Phagwara, Punjab (India), for the award of the degree of **Doctor of Philosophy** in **Agronomy (Part time)**.



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Place: Phagwara, Punjab (India) (Registration No:41500100)

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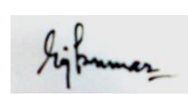

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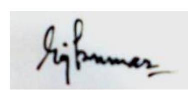
CERTIFICATE I

This is to certify that Prabhjot Singh (Registration No: 41500100) has personally completed the thesis entitled, "**Effect of potassium and copper on yield and quality of potato (*Solanum tuberosum* L.) in a Typic Ustorthent soil in sub - mountain area of Punjab**" under my guidance and supervision. To the best of knowledge and belief, the present work is the results of his original investigation and study. No part of the dissertation has ever submitted for any purpose at any university.

The project report is appropriate for the submission and partial fulfillment of the condition for the evaluation leading to the award of degree of **Doctor of Philosophy** in **Agronomy (Part time).**



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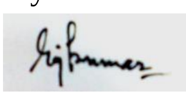
CERTIFICATEII

This is to certify that thesis entitled, "**Effect of potassium and copper on yield and quality of potato (*Solanum tuberosum* L.) in a Typic Ustorthent soil in sub - mountain area of Punjab**" submitted in partial fulfilment of the requirement for the award of degree **Doctor of Philosophy** in **Agronomy (Part time)** to Lovely Professional University, Phagwara (Punjab) is a bonafide research work conducted by Prabhjot Singh (Registration No: 41500100) under our guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigation have been fully acknowledged.



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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviations	Meaning
ANOVA	Analysis of variances
B:C	Benefit cost ratio
Cm	Centimetre
%	per cent
DAT	days after transplanting
DAS	days after sowing
e.g.	example gratia (for example)
Fig.	Figure
FYM	farmyard manure
G	Gram
etal.	Etalii(andothers)
Ha	Hectare
i.e.	id est (that is)
Kg	Kilogram
@	at the rate
FAO	Food and Agriculture Organization
M	Metre
Mg	Milligram
RDF	recommended dose of fertilizer
m^{-2}	per square meter
No.	Number
p.	Page
pp.	Pages
Max.	Maximum
Min.	Minimum
etc.	et cetra (and other things)
Mm	Millimeters
T	Tonne

viz.,	Namely
q ha^{-1}	Quintal per hectare
kg ha^{-1}	Kilogram per hectare
$^{-1}$	Per
^{o}C	Degree Celsius
Rs.	Rupees
µg/g	Microgram per gram
mha.	Million hectares
MT	Metric tones
Mg	Milli gram
Q	Quintal
L	Litre
cv.	Cultivated variety
Fed	Feddan
mM	Millimolar
Ppm	Parts per million
Mmol/g	Millimole per gram
Nm	Nanometer
Mu	Unit of land area (1 mu=0.067 ha)
DAG	Days to germination

CONTENTS

EFFECT OF POTASSIUM AND COPPER ON YIELD AND QUALITY OF POTATO (*SOLANUM TUBEROSUM* L.) IN A TYPIC USTORTHENT SOIL IN SUB - MOUNTAIN AREA OF PUNJAB

ABSTRACT

The present study was conducted to evaluate the effect of potassium and copper on the yield and quality of potato (*Solanum tuberosum* L.) in a Typic Ustorthent soil in sub-mountain area of Punjab. The study was conducted during Rabi seasons of 2017-18 and 2018-19 at village Bhulana, Hoshiarpur (Punjab). The field investigation was conducted in randomized block design and consisted of fourteen different applications comprising FYM and the fertilizer dose comprised of N @187 kg/ha, P_2O_5 @ 62 kg/ha, K_2O @ 62 kg/ha and RDF of $CuSO_4$ @ 200g/100L of water. The experiment was conducted with three replications. N and P doses were same in all the treatments while varied fertilizer doses of K_2O were incorporated in the soil along with copper applied @ 75%, 100% and 125%of the recommended dose as foliar spray. Application of potassium, copper and their combination posed insignificant effect on emergence percentage, clearly depicting the negligible impact of treatments on the potato emergence. Treatment combination T_{13} i.e. K_2O (125%) and Cu (125%) foliar application showed positive response on potato crop in terms of growth, yield, quality and economics when compared to other treatment combinations. This dose of potassium and copper increased the plant height, photosynthetic efficiency of potato plant as depicted by increased leaf area index, leading to increased fresh and dry weight, eventually resulting in increased vitamin C, specific gravity, starch accumulation, tuber weight, yield and harvest index. The available potassium content of soil after harvest, potassium content in tuber and haulm and copper content in tuber also increased under the same treatment combination, thereby facilitating the plant roots to absorb higher nutrients and influencing the economics too. Hence, it is recommended that farmers can adopt the application of K_2O (125%) of RDF and copper application in sandy soil to raise the productivity of potato. However, further adaptive research trials are needed to be carried out in sandy soils at different regions in Punjab.

Keywords: copper, potassium, sandy soils, potato, Punjab, Typic Ustorthent

Chapter 1

Introduction

Potato (*Solanum tuberosum* L.) is native of South America and popularly known as "The King of Vegetables". Among various vegetable crops, it occupies the largest area in the world. Ploidy level of potato varies from diploid to pentaploid but the commonly cultivated potato is tetraploid i.e.2n = 48. Potato was first reported to be domesticated in the vicinity of Lake Tritica basin that lies in region of Andes of Peru Bolivian situated in high hills of South America. In the early part of the 17th century through British missionaries or the Portuguese traders, it was introduced in India. It was first mentioned in 1615 by a Mughal King Asaph Khan to Sir Thomas Roe in a banquet at Ajmer. Around 1675, it was first grown in Surat and Karnataka and later in 1822 in the Nilgiri Hills. It has extensive cultivation in Ireland, Germany, Netherland, France, Spain, Romania, Poland, Russia, China, India, USA, South America, Russia and the European countries. After three most popular cereal crops i.e. wheat, maize and rice, potato acquires fourth position as a major food crop with annual production of 19 mha. (Ahmadi *et al*. 2014), worldwide, yielding nearly 19 tonnes fresh tubers per hectare annually (FAOSTAT 2018).

According to recent study, China, India, Russia, the United States and Germany were the largest potato-producing countries worldwide in 2020, producing 78.2 million metric tonne, 51.3 million metric tonne, 19.6 million metric tonne, 18.8 million metric tonne and 11.7 million metric tonne, respectively (FAOSTAT 2020). Potato is grown in almost all part of India, except Kerala, in diversified agro-climatic conditions. About 90 percent of the total potato area is located in subtropical plains, 6 percent in the hills and 4 percent in the plateau region of peninsular region (Chadha 2009). It is grown under short day conditions in winter months from October to March in plains and a small area in the hilly regions where it is grown under long day conditions in summers from April to September. The potato crop can be cultivated in wide range of soil types and is well known to adapt in variety of climatic conditions due to its wide flexibility in planting and harvesting time (Pandit and Chandran 2011), owing to which the crop suits best for intensive cropping systems together with inter cropping common in different areas of the country. Being a *rabi* season crop,it is mainly grown in West Bengal, Madhya Pradesh, Bihar, Punjab, Haryana, Andhra Pradesh, Gujarat, Uttar Pradeshand Tamil Nadu (Rana 2008). Potato is one of the main cash crop of Punjab. In Punjab, potato crop was cultivated on 1.07 lakh hectares with annual production of 29.49 lakh tonnes (Anonymous, 2021), most of which is meant for seed production.

Potato is one of the major ingredients in human diet. The carbohydrate reserve in the form of starch is stored in the modified stem called tubers. The protein content in potato is 524 kg/ha which is quite high in contrast to cereal crop wheat (254 kg/ha) (Dutt 2008, Sazid and Aftab 2009). The major component of fresh weight of potato is water accounting for nearly 80% water while the remaining dry matter is starch. Potato tubers contain approximately 0-2% total soluble sugars, 13-16% starch, 2% protein, 0.5% fibre, 0.1% lipids, 20% dry matter, 22-25% amylose, 1-1.5% ash and trace amounts of minerals, vitamin sand anti-nutrients such as glycolalkaloids (Kumar *et al.* 2013). It contains considerable amounts of iron and zinc along with sufficient amount of B-vitamins and minute amounts of elements like selenium, boron, chromium, copper, manganese and molybdenum. Owing to its highly significant dietary importance and crop production prospective, it is capable to sustain mushrooming population of world and thus contribute towards elimination of problems related to nutrition and starvation. Potato can be observed in different colors such as white, pink, yellow, purple, red and blue because of the presence of anthocyanins.

Owing to direct consumption of potato, it needs to possess paramount excellence parameters (Roma *et al.* 2017 and Sierra *et al.* 2017). The quality of tubers depends upon chemical composition of tubers that is determined by genetic and environment factors and affects plant metabolism (Baranowska *et al.* 2017 and Garrido *et al.* 2017). The requirement of nitrogen in potatoes is estimated to be 80-130 kg per hectare. However, it is reported that 10 tonnes of tubers requires the uptake of N @ 40-50 kg, P @ 8.8 kg, K @ 22 kg and Mg @ 8.4 kg (Dvorak *et al.* 2016).

In potato mineral administration is pivotal to attain optimal yield and quality of tubers. High nutrient requirement is demanded in potato crop to form plentiful vegetative biomass and superior capacity of tubers present in a unit area. It consumes macronutrients such as nitrogen, phosphorus, potassium, magnesium, calcium and micronutrients like zinc, copper and boron. Therefore, treatment of most favorable nutrient doses in reasonable amount is the prime need for high potato yields (Poljak *et al.* 2007). Agricultural production of India profoundly relies upon fertilizer doses that result in disintegration of nutrient, ultimately affecting quality of soil. Also, continuous exhaustion of reserves of nutrient from soils resulted in various deficiencies related to nutrients. Mostly Indian soils are found to be scarce in microelements i.e. boron, zinc, iron and manganese, the competence of inorganic microelements is quite little as a result of their fixation in the soil. Therefore, soil nutrient stores and application of basal fertilizers does not meet the demands of crops at all times. Different types of nutritional disorders have been reported in acidic and alkaline soils in case of potato cultivation, this might be due to lack of calcium, magnesium and phosphorus in acidic soils and lack of boron, manganese and zinc in alkaline soils that are crucial for development of crop. Apart from fertilization, another medium to supply nutrients is foliar spray to leaves of plant. Micronutrients play variety of roles in plants as they contribute toward higher photosynthetic activity by increasing the content of light harvesting complex of leaves, which thereby intensifies further processes in plants (Marschner 1995). Foliar application of nutrients like copper, zinc, molybdenum, manganese and boron in potato elevated nitrogen, phosphorus, potassium uptake with concomitant rise in chlorophyll content in leaves, eventually leading to promotion of tuber development and improved yield (Meng *et al.* 2004).

Potato mostly depends upon availability of soil potassium as it is reported that tubers withdraw approximately nitrogen (1-5 times) and phosphate (4-5 times). Therefore, potato is called a marker crop for potassium accessibility as it requires higher amounts of potassium (Fageria *et al.* 1997 and Panique *et al.* 1997). Potassium plays many roles as it is involved in translocation of sugar and contributes toward production of starch in plants. As potato tubers possess high starch content, potassium is significant mineral involved in the development of tubers. Potassium also plays central role in photosynthetic processes and favors high energy status, mediates opening and closing of the stomata, translocation of minerals, water uptake, vitamin C and organic acid contents in plants. Sufficient potassium levels in plants help them to regulate stomatal opening and thus aid to resist water stress under drought conditions. It too plays a vital role in leaf extension, stem elongation and regulating turgidity of plant cells due to its contribution in turgor maintenance. It is also called as 'quality element' as it influences size, shape, color, taste and shelf life. Potassium prevents physiological disorders like internal blackening, hollow heart, bacterial and fungal diseases and also lessen the chance of infection by enabling potato plant to prompt recovery from disease attack. Moreover, it enhances the shipping quality and improves the shelf life of potato. Overall, potassium contributes toward various biochemical processes such as photosynthesis and starch synthesis, which ultimately regulates tuber quality and also enhances tolerance against biotic and abiotic stress (Ebert 2009).

Along with the macronutrients the use of micronutrients is as essential for plant growth and development as the macronutrients. Trehan and Grewal (1997) revealed that NPK doses along with micronutrients resulted in optimal and higher yields. The micronutrients include copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), boron (B), molybdenum (Mo) and chlorine (Cl) that plays an unambiguous part in the growth and development of a plant. Although, these nutrients are required in trace amounts, many soil types do not supply them in adequate amount for proper development and favorable yield of potato.

The exploitation of high analysis NPK fertilizers and high yielding potato cultivars with high nutrient demands along with decreased accessibility of farmyard manure in rigorous arable agriculture have contributed in escalating the load made on the soil in terms of its ability to supply micronutrients to plants. So, it has become obvious to use essential micronutrients in cultivation of potato to get outstanding production as well as performance of crop.

Soil acts as pool for the availability of all the indispensable micronutrients needed for the normal growth of potato crop. Therefore, the knowledge of amount of micronutrient deficient potato growing regions is very important. Zinc is the scarcest micronutrient in potato growing areas, followed by copper iron and manganese. Copper regulates cell wall metabolism, photosynthetic rate, phosphorylation, electron transport chains in the respiratory system (Yruela 2009), signaling mechanism and iron mobilization in the cells of plants (Yruela 2005). Higher concentration of copper retards growth of plant and proteins activity (Morelli and Scarano 2004) while optimize concentrations increase plant growth and development (Verma *et al.* 2011 and Syuhada *et al.* 2014). Copper application lowered the photosynthetic, respiratory rate and as well as affected the growth and development of young leaves, stigma and stamens (Yruela 2005, Syuhada and Jahan 2016). In an investigation carried on 121 fields of Jalandhar (Punjab), the response of potato to Zn, Fe and Cu was observed to be 57%, 40% and 38% with the mean response of 21, 21 and 24 q ha^{-1}, respectively (CPRI 2008). Additionally, potato leaves possessing high contents of copper, zinc or manganese showed low intensity of disease and evidently rate infection of late blight also reduced (Bhattacharyya *et al.* 1990). In another study, foliar spray with copper or boron helped to increase the storage of *Jerusalem artichoke* tubers followed by low rate of weight loss and decay (Samy *et al*. 2015).

Nowadays most of the farmers are aware of essential macronutrients but still the knowledge of micronutrient is lacking. Although some farmers are applying zinc, manganese fertilizers in their fields but the use of copper is lacking. Moreover, the interaction of micronutrients with macronutrients also affects their availability. Various interactions have been observed among potassium and micronutrients (Singh *et al* 2017) and some of these reported with Zn have already been noted. Nonetheless, when potassium was added, interaction with micro elements like B, Fe and Mo caused decreased uptake while use of potassium increased micronutrient utilization for other nutrients like copper (Cu), Mn and Zn (Dimkpa and Bindravan 2016). Keeping in view the significance of potassium and copper on productivity of potato, the present study was planned by taking into consideration the succeeding goals:

1. To evaluate the effects of different levels of potassium and copper fertilizers on growth, yield and quality of potato
2. To find the optimum dose of potassium and copper fertilizers
3. To evaluate the comparative economics of different treatments.

Chapter 2

Review of literature

A concise review of the findings related to 'Effect of potassium and copper on yield and quality of potato (*Solanum tuberosum* L.) in a Typic Ustorthent soil in sub - mountain area of Punjab' is presented in this chapter. Several macro and micronutrient sources have remarkable influence on the growth and yield parameters of potato. In the present text, an effort has been made to appraise the relevant investigations done before under following captions:

2.1 Effect of potassium on growth, yield and quality attributes

2.1.1 Growth and development

2.1.2 Yield attributes

2.1.3 Quality attributes

2.1.4 Soil and plant analytical parameters

2.1.5 Economics

2.2 Effect of copper on the growth, yield and quality attributes

2.2.1 Growth and development

2.2.2 Yield attributes

2.2.3 Quality attributes

2.2.4 Soil and Plant analytical parameters

2.2.5 Economics

2.1 Effect of potassium on growth attributes:

2.1.1 Growth and development

Potassium is an indispensable macronutrient that plays pivotal role in plant growth and metabolism. It has an exceptional role in plants owing to its extraordinary osmotic potential. On the basis of its unique effects, it contributes toward the growth of cell, leaf area expansion, elongation of root (Mengel and Arneke 1982, Song 2017, Jordan-Meille and Pellerin 2004, Torabian *et al.* 2021) and mediates opening of stomata and also mediate phototropism (Ahmad and Maathuis 2014). Potassium posed negligible impact on growth attributes of crop in initial periods of crop development while at 75 days after sowing potassium treatment @ 150 kg/ha led to increased leaf area index and contributed in maintaining leaf area in anticipation of maturity (Saika *et al.* 1987) Moreover, it was also found that potassium had a favorable effect on the tuber dry matter production in contrast to control. However, potassium application @ 100 kg/ha led to increased dry matter accumulation (432.20 g/m^2) at the time of harvesting while minimum (342.10 g/m^2) was observed under control condition.

Krishnappa (1990) working at Bangalore in sandy loam soil, found that the emergence of seed tubers was 92 to 96% under different treatments which revealed that potassium application played nil role towards tuber emergence, suggesting the low salt index of potassic fertilizer to be a reason. Similar observations were also reported in field experiments of potato (Ayyub *et al.* 2011, Noor *et al.* 2011).

Bansal and Umar (1998) conducted a research to study the impact of potassium treatment on dry matter content of tuber. Potassium application @ 225 kg/ha produced highest dry matter (22.4%). However, non-significant differences among results of potassium applications @ 225 and @ 150 kg/ha were found.

Khandakhar *et al.* (2004) investigated a potato related study to evaluate the significance of potassium on germination percentage, plant height and stems per hill. The observations indicated that germination percentage was non-significantly influenced by potassium application (60-100 kg/ha.). However, potassium treatment increased plant height from 45.29 cm to 54.76 cm at 60 days after planting. Additionally, number of stems per hill (3.57 to 3.85) was found to increase with rising potassium concentration. Similarly, potassium application @ 40 to 120 kg/fed (where fed i.e. 1 Feddan = 1.038 acres) caused significantly higher number of stems/plant. However, at 90 DAP potassium application @120 kg/fed resulted in 5.24 stems per plant where as minimum of 4.30stems per plant were observed when potassium was supplied @40 kg/fed (Mahmoud and Hafez 2010).

Adhikary and Karki (2006) reported that potassium treatment had a significant role on growth attributes of potato varieties (Ajiba, Zafira and Picasso). The plant height, number of aerial stems and number of leaves/plant were found to increase significantly by elevating potassium dosage from 0 -150 kg/ha. Likewise, Al-Moshileh and Errebi (2007) found that application of potassium sulfate (K_2SO_4) @ 450 kg/ha led to maximum rise in plant height (46.33 cm).

Bose *et al.* (2008) elucidated the role of varying rates of potassium @ 0, 60 and 120 kg/ha on performance of tubers. The maximum plant height, fresh weight, number of sprouts, number of leaves, stolons, tubers and tuber yield was observed under potassium application @120 kg/ha in contrast to potassium application @60 kg/ha.

Kupe *et al.* (2009) carried an investigation in Romania to elucidate the effect of potassium (K) fertilizer treatment in potatoes. The treatments comprised different doses of potassium fertilizers (0, 50,100,150 and 200 kg/ha) in soils with medium concentration of nitrogen and potassium. The phenology, growth dynamics, number of shoots, number of tubers, resistance to diseases, indication of production, economic evaluation and starch content were determined. Based on this indication, it was concluded that the best recommended rates were the 150-200 kg K/ha treatments.

The effect of potassium @ 40 K_2O/ha, 80 K_2O/ha and 120 K_2O/ha on the growth and production of potato was studied by Asmaa and Magda (2010).Increasing levels of potassium doses from 40 to 120 kg K_2O/ha caused maximum increase in plant height, fresh/dry biomass, number of leaves and potato yield considerably.

Abd EI- Latif *et al.* (2011) reported that the 120 kg K_2O/feddan (1 feddan = 1.038 acres) led to significant differences in plant height as compared to studied conditions. Dkhil *et al.* (2011) analyzed the role of potassium spray on plant vegetative stage performance and observed that escalating K_2O concentration from 0 - 0.95 g L^{-1}caused considerable enhancement in the height of potato plant. However, increased plant height was observed from 45thday after planting until 95thDAP and 0.95g K_2O/L led to highly variable differences in height of plants (79.1 cm at 95 day) when compared with other treatments.

Hussain *et al.* 2011 elucidated the effect of varying concentration of potassium i.e.0 -120 kg SOP $ha^{-1}$was studied. Plant height was observed to be highest under potash dose of 90 kg SOP/ha while lowest was recorded under control. Another experiment on potato cv. Kufri Ashoka depicted that application of potassium@120 kg K/ha and @160 kg K/haled to increased plant height (Singh and Raghav 2000).

Addition of potassium fertilizer (K_2SO_4) in soil led to increased potato shoot growth (Ati and Nafaou 2012). The length of plant and LAI increased significantly with irrigation levels. It was observed that shoot length and LAI was85.76 cm, 41.22 cm^2/plant and 74.23 cm, 34.78 cm^2/plant under different levels of irrigation when half and quarter to half percent of available water was depleted, respectively when potassium was applied @600 kg K_2SO_4/ha.

Nitrogen and potassium levels had negligible effect on plant emergence (Singh and Lal 2012). Potassium was reported to pose variable impact on shoot height, number of leaves/plant and chlorophyll content. It was recorded that potassium application @100 kg K_2O/ha significantly increased plant shoot height, leaf number and chlorophyll content. The stems/plant were negligibly affected by nitrogen and potassium levels asthis trait highly depends upon variety, size of seed and physiological status of crop. While, Lakshmi *et al.* (2012) found that fertilizer doses of 180 kg N/ha + 180 kgK_2O/ha resulted in increased plant height, number of shoots /plant and the observations recorded under treatment combination (180 kg N/ha + 180 kg K_2O/ha) remained at par with treatment @ 180 kg N/ha + 120 kg K_2O /ha. Jasmin (2013) reported that plant length drastically improved upon foliar spray of high potassium concentration as compared with the control treatment with no spray.

Tang *et al.* (2015) conducted an experiment on three varieties of sweet potato *(Ipomoea batatas* (L.) Lam.) under potassium lacking soil and elucidated that deficiency of potassium resulted in reduced biomass productivity and root yield. Daniel *et al.* (2016) while conducting research at Kenya found that potassium had positive role on growth and yield parameters. Increasing potassium levels from 0 to 150 kg K_2O/ha led to increased stem number, leaf number/plant and plant height. Zelelew *et al.* (2016) conducted an investigation to study the effect of five potassium doses in potato (*Solanum tuberosum* L.) growth and observed that potassium dosage from 0 kg to 150 kg/ha led to maximum rise in shoot height, stem number and number of leaves/plant. Singh *et al.* (2018) found that treatment combination of NPK (100%

RDF)resulted in increased plant height (69.02 cm), leaf area index (4.36), 54.97compound leaves, 12.90 branches/plant, 8.67 plants in running meter, 4.17 main stems/hill and79.20g dry weight of haulm/hill.

Panthi*et al.* (2019) investigated the influence of potassium dosage @ 30, 40, 60, 80 and 100 kg K_2O/ha in two varieties of potato (Local and Cardinal). In both varieties, potassium application@ 100 kg/ha resulted in largest canopy, increased the stem diameter and leaf length.

In another experiment, Bera *et al.* (2019) found the N and K_2O application as basal + 1/4 at 28 and 42 days after planting(DAP) @ 200:150:150 $N:P_2O_5:K_2O$ $kgha^{-1}$ resulted in highest growth parameters namely plant height (36.17 cm), leaf area index (3.12), growth rate of crop (40.04g m^{-2} day^{-1}), net assimilation rate (6.04g m^{-2} day^{-1}) and leaf area duration (132.53 days).

2.1.2 Yield attributes

Potassium fertilization poses differential influence on the yield of potato. Studies indicated that high levels of potassium led to considerable effect on potato tuber yield (El-Gamal 1985, Humadi 1986), as potassium increased the supply of photosynthates that resulted in large sized tubers and also increased the number of tubers/plant (Goswami 2002). However, another study conducted by Trehan *et al.* (2001) showed the positive influence of potassium on size while yield remains unaffected. Similar results were found in field trial conducted by Westennann (2005) where insufficient potassium resulted in smaller-sized tubers.

Hosseinpour and Malakouti (1996) observed that application of potassium @ 150 kg/ha led to potato yield of 50 t/ha. Likewise, Bansal and Umar (1998) found that with potassium application@ 150 kg/ha resulted in increased tuber yield to 33.95 t/ha. Similar observations were recorded in earlier studies (Singh *et al.* 1993, Singh and Singh 1995).

Dubey *et al.* (1997) found that potassium treatment @ 100 kg per hectare produced maximum tuber yield (31.40 t/ha) and minimum tuber yield (22.50 t/ha) in contrast to control. Also, a consistent increase in the tuber yield was found with potassium application up to 50 kg/ha. Singh and Bansal (2000) found that potassium @ 120 kg/ha resulted in maximum tuber yield (24.2 t/ha) of potato cv. Kufri Bahar. Similarly, when potassium was applied @ 100 kg/ha, highest yield (122 t/ha) was obtained and depending upon the observations recorded the optimal dosage of potassium was framed out to be 98.4 kg/ha resulting in yield of potato 110q/ha (Deka and Dutta 1999).

Shahid and Moinuddin (2001) found that potassium @ 120 kg K_2O resulted in significant increase in potato tuber yield while in another experiment potassium treatment @100 kg K/ha resulted in increased tuber yield (Adhikhari and Sharma 2004). Likewise, Adhikary and Karki (2006) analyzed the results of three years experiment conducted in Nepal and concluded that potassium @100 kg/ha resulted in maximum of 13.72 tubers/plant and maximum tuber weight of 473.33 g/plant, thus influencing positively the yield parameter.

Harvest index was found to be negatively correlated with potassium applicationi.e.0 to 200 kg/ha. For instance, potassium application @ 200 kg/ha led to decreased harvest index from 89.7% to 78.8% when compared with control (Kumar *et al.* 2005). In a field experiment carried out on potato cv. Kufri Pukhraj at Patna during 2009-10, it was found that potassium treatment @ 100 kg/ha as MOP led to considerable increase in the number of marketable and total tubers. The tuber yield in terms of number of tubers with potassium application @ 100 kg/ha was found to be maximum i.e. 548770 per hectare as compared to control (524420 per hectare) (Bansal and Trehan 2011).

Chopra *et al.* 2010 found that nitrogen treatment led to differential variation in number of tubers/plant, weight of tubers/plant and tuber yield whereas potassium application resulted in increased number of tubers and tuber yield. Singh (2010) reported that application of potassium @ 100 kg K_2O per hectare led to radically higher tuber yield along with the marketable yield. Haile and Boke (2011) observed that potassium application @ 150 kg/ha resulted in increased tuber yield (53 t/ha) as compared to control (18t/ha). Similarly, Haile and Mamo (2013) found that potassium concentration significantly influenced the total and marketable tuber yield of potato. These results are in confirmative with Shunka *et al.* (2017).

A study was conducted to elucidate the relative influence of source, concentration and method of application of potassium on yield or excellence parameters of potato (Khan *et al.* 2010). It consisted of three treatments of K_2O @ 0, 150 and 225 kg/ha from potash sources (SOP and MOP). The foliar application of potassium (1% K_2O) was carried out at 30, 45 and 60 DAG and K_2O @150 kg /ha was supplied in soil. The results depicted that potassium application @ 150 kg/ha as K_2O from SOP and MOP resulted in increased tuber yield when compared with nitrogen and phosphorus application. However, results were found to be non-significant with K_2O @ 225 kg/ha in comparison to 150 kg K_2O/ha. In another study, a field experiment was conducted on potato cv. Kenne beck to analyze the role of top dressing on the yield (Zhu *et al.* 2010). The study consisted of four treatments, control (C): DAP 16 kg + urea 15 kg + K_2SO_4 15 kg/mu [1 mu =0.067 ha], T1: DAP 16 kg + urea 8.6 kg + K_2SO_4 15 kg/mu along with fertilizer dressing of urea 6.4 kg/mu, T2: DAP 16 kg + urea 15 kg + K_2SO_4 7.5 kg/mu and with fertilizer dressing $K_2SO_4$7.5kg/mu),T3: DAP 16 kg + urea 8.6 kg + K_2SO_4 7.5 kg/mu and with fertilizers dressing urea 6.4 kg + K_2SO_4 7.5 kg (T3). The yield was the highest when potassium fertilizer was dressed and the yield was the second highest when nitrogen, potassium fertilizers were dressed, but the two treatments not differed significantly. Results depicted that dressing with NK fertilizers led to high percentage of marketable tuber yield. Abd El-Baky*et al.* (2010) reported that potassium fertilizers @ 60 - 150 kg K_2O/ha resulted in significant increase in yield. Additionally, positive correlation was observed among potassium and yield parameters i.e. total yield/plant and yield/fed. Abd El-Latif *et al.* (2011) studied the effect of potassium concentration on yield of tubers and revealed that plants treated with 120

K_2O kg/fed showed highest significant values as compared to other treatments of potassium fertilizer. Dkhil *et al.* (2011) analyzed that the potassium spray caused negligible effect on tuber number, showing non-significant differences among treatments in terms of tuber yield. However, foliar application of potassium resulted an increase in the total tuber yield (1454 g/plant) as compared to control (1246 g/plant).

A two year field trial was carried out at the research farm of Lebanon to study the yield responses and tuber quality of potato was analyzed (*Solanum tuberosum* L. cv. Agria). The treatments comprised of four levels of potassium (0, 75, 150 and 225 kg K_2O/ha) and two timings of application (tuber initiation and bulking) in split-plot design. The increasing dosage of potassium treatment from 0 - 225 kg K_2O/ha drastically changed the potato yield and its yield attributes. Cumulative results showed that in both years, increasing potassium fertilizer to 150 kg K_2Oha^{-1} caused quadratic increase in small grade tubers and aggregate tuber yield, eventually resulting in a plateau, depicting luxurious utilization of the nutrient at 225 kg K_2O/ha (Karam *et al.* 2011).

Potassium doses up to 600 kg K_2SO_4/ha led to variably high marketable tuber yield (Ati and Nafaou 2012). Increasing potassium rates at a rate of 600 kg K_2SO_4/ha improved yield to 30.26 and 25.66 t/ha. Singh and Lal (2012) found that nitrogen dose @ 150 kg/ha and potassium dose @ 100 kg K_2O/ha resulted in significant increase in the harvest index and bulking rate. Potassium fertilization @ 100 kg K_2O/ha progressively enhanced the aggregate as well as large and medium grade tuber yield. Yield of Potato was estimated to be 22.2, 29.0, 32.3 and 33.5 t/ha as a result of potassium fertilizer (0, 50, 100 and 150 kg K_2O/ ha) and the percent increase estimated was 36.6, 44 and 45 percent respectively in contrast to control. The yield of large sized tubers increased by 35.3, 49.5 and 53.4 percent at 50, 100 and 150 kg K_2O/ha, respectively in contrast to control with simultaneous less production of low grade tubers. The number of large and medium grade tubers was found to be highest under potassium application of 150 kg K_2O/ha.

Another study was conducted on varied doses of potassium from sulphate and muriate of potash i.e from 0, 150 and 225 kg Kha^{-1} and uniform doses of N and P were applied. The results depicted a major rise in yield of tuber influenced the marketable potato tuber yield when potassium from both the sources was supplied @ 150 kg K/ha. However, this was found to be statistically non-significant when both the doses were compared. Also, among both the sources the increase in yield was comparatively high when MOP was applied in contrast to SOP (Khan *et al.* 2012).

Jasim *et al.* 2013 observed the role of fertilizer spray (high in potash) on potato genotypes. It was found that potassium treatment led to higher no. of tubers $plant^{-1}$ and also contributed towards increased tuber weight which ultimately increased tuber yield.

Manolov *et al.* 2015 conducted a pot study for evaluating the response of potato for increasing doses of potassium either as K_2SO_4 or potassium chloride@ 0, 200, 400 and 600 mg K/ kg soil. The sources for nitrogen and potassium were $NH_4NO_3$and Ca $(H_2PO_4)_2.H_2O$. The observations showed that the effects were more prominent under treatments with KCl. Pulok *et al.* (2016) revealed that dose of potassium @ 125 kg/ha resulted in maximum yield and benefit cost ratio. Kumar and Chandra (2018) reported that nitrogen dosage @ 150 $kgha^{-1}$ and dosage of potassium @ 100 kg K_2O/ha increased the harvest index and bulking rate.

2.1.3Quality attributes

The contents of sugar were found to be higher in potato tubers treated with potassium in contrast to N and P (Khan *et al.* 2010, Kamal *et al.* 1974). The significant variation in contents of reducing sugars were narrower in potato tubers when different levels of potassium as muriate of potash was applied as compared to dose when different levels of potassium with application of sulphate of potash was supplied. It was further concluded that higher doses of potassium led to lowered contents of reducing sugars by activating starch synthesis (Bansal and Trehan, 2011, Gerend as *et al.* 2007, Nikolova and Blagoeva 2000, Marschner 2012, Ali *et al*. 2021). The contents of starch were found to increase in tubers when application of moderate potassium fertilizer was carried out in contrast to the tubers that received low potassium fertilization (Baniuinene and Zekaite 2008). Nonetheless, the contents of total soluble sugars remained unaffected by potassium fertilizer dose (El-latif *et al.* 2011).

Starch contents in tubers have been found to be positively correlated with application of potassium and nearly 1.8 % potassium was recorded in dry matter of tuber (Bansal and Trehan 2011). Baniuniene and Zekaite (2008) reported that higher dosage of potassium fertilizers lessened the contents of starch and dry matter in potato tubers by average 1.3-2.2 and 0.9-2.4, respectively in contrast to control or tubers treated with sole supply of nitrogen and phosphorus. Whereas, Terman (1950) investigated that increased potassium application led to consistent reduction in the contents of starch in potato tubers. This could be due to some other factors like genetic variation, environmental conditions and methods of tuber storage (Olsson *et al.* 2004).

High starch contents were reported in tubers of potato where plants were subjected to potassium treatment as compared to untreated. This is due to starch-sugar inter-conversion in potato tubers. Basically, the starch hydrolysis in potato results in sweeter potatoes which is an undesirable trait. The inter-change of starch and sugar varies with temperature and potassium fertilizer etc. (Bhattari and Gautam 2006). In lower doses of potassium, there is inter-change of starch to sugar while opposite is observed under high doses of potassium fertilizer and no synthesis of sugar is reported under moderate dose of potassium (Marschner 1995).

One of the indispensable vitamins found in tubers of potato is vitamin C (Hamouz *et al.* 2009). Fertilizer application affects the contents of ascorbic acid in potatoes, hence it is important to gain information about the effects of fertilizer dosage on vitamin C. In an experiment conducted by Smith and Smith (1977) in Poland, results showed that potassium dosage @ 50 kg Kha^{-1} increased the levels of ascorbic acid while 100 kg Kha^{-1} posed no visible effect. However, reduction in contents of vitamin C was reported under potassium application @150 and @300 kg K/ha. The contents of vitamin C were reported to increase under potassium application as sulphate of potash and muriate of potash@ 150 kg K/ha by 10.8% and 14.7%, respectively. The differences in ascorbic acid contents in relation to source of potassium were significant, whereas for the levels and method of application it appeared to be non-significant (Smith and Smith 1977). In a pot experiment, it was found that KCl treated potato tubers contained lower vitamin C content in contrast to control and K_2SO_4 treated tubers. It clearly depicted the negative effects of KCl on contents of ascorbic acid in potato tubers. For instance, potassium chloride treatment @200 mg Kkg^{-1}soil reported to diminish the contents of vitamin C to 46% while KCl fertilization @ 400 mg and 600 mg K/kg soil lessen the contents of ascorbic acid to half (Manolov *et al.* 2015)

One of the quality measures of potato tubers is the specific gravity that is closely linked with starch content, dry matter accumulation and meeliness (Teich and Menzies 1964). The specific gravity has been correlated positively with phosphorus as well as potassium fertilization (Al-Moshileh and Errebi 2004). Nonetheless, potassium fertilization in excess rates reduced specific gravity (Davenport *et al.* 1999, Laboski and Kelling, 2007). Similarly, another study too reported decrease in specific gravity with increasing rates of potassium fertilizers in potato (McDole 1978, Westerman *et al.* 1994). However, Al-Moshileh and Errebi (2004) disagreed with these beliefs and elucidated that potassium application had no relation with specific gravity. Pervez *et al.* 2013 found that total soluble solid (TSS) level was also significantly influenced by potassium application. The specific gravity increased significantly upon potassium application @ 150 kg/ha while decreased when higher rate of potassium application was carried out @ 225 kg/ha (Khan *et al.* 2010). Similarly, potato crop treated with higher doses of N and K too possessed lower specific gravity in their tubers (Beukema and Vander 1991, Maier *et al.* 1994, Westermann *et al.* 1994). Adhikari and Sharma (2004) also showed that high dosage of N and K beyond threshold level in experimental area of potato caused marked decrease in specific gravity. Therefore, specific gravity of potato is a trait influenced by variety of potato under study, climatic condition and experimental region etc. Laboski and Kelling (2007) deduced that potassium application plays pivotal role towards specific gravity of potato tuber.

Specific gravity is not only a factor that relies on dosage of potash fertilizer but may depend upon source of fertilizer. For instance, the specific gravity is affected to a large extent with SOP as compared to

MOP. The specific gravity was reported to be higher when potato was treated with SOP in comparison to MOP (Khan *et al.* 2012). On the contrary, potassium chloride (KCl) posed somewhat unfavourable effects and reduced dry matter content of tubers (Bansal and Trehan 2011). Khan *et al.* (2010) found that high potassium concentration above 2% in potato tuber lowered the dry matter content by affecting physiological and biochemical status of plants.

Potassium influences the size of tubers and lead to increased proportions of large tubers in contrast to small ones (Manolov *et al.* 2015, Singh *et al.* 2020). It makes tubers to grow large size and gain weight as found in a study where progressive increase was observed in aggregate tuber yield of medium and large grade tubers. On the contrary, small-grade tubers yield showed an opposite trend. This could be as a result of stimulatory effects of potash on physiological parameters such as photosynthesis, solute translocation and starch production inside the storage tubers that eventually contributes towards bulking of the tubers (Marschner 1995).

2.1.4 Soil and plant analytical parameters

Potato is largest consumer of potash and withdraws nitrogen and phosphate nearly 1.5 times and 4-5 times, respectively (Bansal and Trehan 2011). In India, experiments conducted by Potash Research Institute of India and Central Potato Research Institute (CPRI) showed potato response toward potash fertilization and found increase in yield parameters.

Abd El-Baky *et al.* (2010) found that increased potassium rates led to considerable rise in contents of potassium and zinc in sweet potato leaves. Highest potassium and zinc contents were observed in plants that received 150 kg/K_2O in contrast to other treatments. Abd El-Latif *et al.* (2011) depicted that nitrogen content in leaves increased significantly upon addition of 96 kg K_2O/feddan than other treatments. Contents of potassium in leaves were significantly affected by all studied potassium doses when compared with control treatment, while the phosphorus content in leaves remained unaffected. Further, it was revealed that nitrogen content in tubers increased significantly upon addition 96 K_2O kg/feddan whereas phosphorus content increased when 72 K_2O kg/fed. was applied. High levels of potassium fertilizers @120 K_2O kg/feddan led to increased contents of potassium in tubers while lowest contents of nitrogen, phosphorus and potassium were recorded in control (without addition of potassium fertilizers). Nitrogen and potassium uptake increased with increasing levels of potassium doses (Singh and Lal 2012).For instance, among different potassium doses potassium @ 150 kg K_2O/ha led to increased uptake of nitrogen (116.2 kg/ha) and potassium (167.2 kg/ha). Fertilizer treatment of potassium @ 100 kg K_2O and nitrogen @ 150 kg N/ha led to higher recovery efficiencies of potassium (REK) and increasednutrient use efficiency of nitrogen fertilizer in potato, thus showing positive correlation between nutrient uptake and yield. However, potassium application@ 150 kg K_2O/haled to reduction in recovery efficiency of potassium (REK) and nitrogen use efficiency when nitrogen application was raised to 225 kg/ha. Increasing levels of potassium application increased nitrogen and potassium uptake in tubers at each level of nitrogen.

Sati *et al.* (2017) found that the increased dosage of potash and split treatment led to improved potash uptake as compared to control and recommended dose (i.e. basal only), owing to more potash required by potato crop for tuberization and bulking, while the split application lessen the leaching of fertilizer, due to which potassium may have easily uptaken through stomatas as foliar application availed the required amount. Adhikary and Karki (2006) found outperformance of potato with regard to uptake of potassium in split application of potash as soil application + top dressing or soil application + foliar spray. Similarly, Maity and Arora (1980) analyzed that potassium application increased the content of potassium and also enhanced uptake of potassium in haulms and tubers. It was further reported about 50% of the total potassium was uptaken during 60-90 days after sowing. It was further supported by Karam *et al.* (2009) and Singh and Lal (2012).

2.1.5 Economics

Haile and Boke (2011) observed that the maximum net profit and insignificant return rates were obtained from potassium applied at 159 kg/ha. A significant positive response of potato crop was obtained with application of potassium and on the same side the highest biological and economic yields were obtained when potassium was applied @ 150 kg/ha.

Kumar *et al.* (2005) while conducting research in Modipuram revealed that by applying potassium @ 150 kg/ha, maximum net returns were obtained. Pulok *et al.* (2016) deduced that potassium application @ 125 kg/ha resulted in high benefit cost ratio.

Zelelew *et al.* (2016) found that potassium application increased the gross margin in potato varieties for every supplementary erratic cost. The maximum gross margin obtained with treatment @ 300 kg K_2O/ha in case of Ajiba cultivar was13,665.816 USD/ha. The observed increase in gross margin might be due to the positive response of potassium towards yield of the experimental varieties.

The economics of potato as influenced by variety Kufri Pukhraj with 150 kg K_2O/ha yielded the highest gross income of Rs. 2,21,217.78 during the year 2016-17 and 2,65,213.89 during the year 2017-18 with net return of Rs. 68,114.78 during the year 2016-17 and 1,12,110.89 during the year 2017-18 and benefit cost ratio of 1.44 during 2016-17 and 1.73 during the year 2017-18. The positive responses might be due to the fact that farmers of Terai zone grew early duration variety like Kufri Pukhraj and cultivated potato during late planting condition with high dose of potassium @150 kg K_2O/ha (Behera *et al.* 2019). Daniel *et al.* (2016) while conducting research at Kenya observed that potassium posed important effect on growth and yield attributes. Potassium concentration ranging from 0-150 kg K_2O/ha resulted in increased no. of stems, leaf number plant^{-1} and plant height. The data of economic analysis clearly indicated that application of 300 kg K_2O/ha resulted in maximum gross margin of 13,665.816 USD/ha. It was further emphasized that potassium fertilizer positively influence the growth and tuber yield of potato.

2.2 Effect of copper on the yield and quality of potato

2.2.1 Growth and development

Kumar *et al.* (2008) conducted a field trial in 2003-04 to find the effect of various micronutrients on growth and yield of potato (*Solanum tuberosum* L.) cultivars in black soils. The micronutrients for field trial comprised of zinc sulphate (0.05%), copper sulphate (0.05%) and magnesium sulphate (0.05%) along with a control treatment. $ZnSO_4$ (0.05%) treatment resulted in maximum (21.4 tonnes) tuber yield/ha over $CuSO_4$ (20.0 tonnes) and $MgSO_4$ (18.7 tonnes). Among the various cultivars under study, 'KufriPukhraj' respondedbest to $ZnSO_4$treatment in terms of growth and yield parameters.

Jobori and Hadithy (2014) & Isreal and Abde (2021) revealed that micronutrient application laid marked impact on potato growth attributes as tuber number plant^{-1} and dry matter percentage was found to increase when full concentration of micronutrient was supplied. Yao (2014) illustrated that foliar spraying of copper fertilizer significantly increased copper concentration in the pepper plant compared to spraying water. Another study showed that copper oxychloride treatment @ 5.00 gL^{-1}showed positive effect on potato at the moment of harvest, which led to increased leaf area, dry matter of leaf blade and yield of tuber dry matter (Ferreira *et al.* 2014).Sarker *et al.* (2018) analyzed that application of zinc and boron affected various parameters i.e. growth and yield of potato whereas micronutrients such as copper, manganese, iron and molybdenum posed non-significant effect. However, combined application of all micro-nutrients i.e. molybdenum, zinc, copper, manganese, iron and boron played exceptional function in plant development and production.

According to Cambrolle*et al.* (2012) and Kumari and Kumari (2021), plants cultivated under high copper levels resulted in chlorosis and retarded growth. However, plants grown under different concentrations of copper i.e 0.041 and 0.082 mM showed negligible effects on growth attributes while copper concentration (0.164 mM)resulted in drastic decrease in branch length (29%), leaf number (56%) and leaf area (21%) (Cuchiara *et al.*(2015).

2.2.2 Yield parameter

Application of zinc, manganese, iron and copper positively affected all characteristics of potato relating to yield components, yield and dry matter percentage (Jobori and Hadithy 2014, Sedlák *et al.* 2022). However, micronutrient mixture application resulted in increased yield 22.89 ton/ha, approximately 8.74% greater in contrast to control. Nonetheless, application of half concentration decreased yield of potato tuber to 20.01 ton/ha.

2.2.3 Quality

The growth of plant is totally dependent upon the availability of copper as it plays significant role in mediating various biochemical reactions in plants. Copper acts in regulating various metabolic and physiological functions like respiration, photosynthesis, protein synthesis, lignifications, phenol metabolism and regulation of plant hormones like auxins by acting as stable cofactor in various enzymes and proteins etc. In plants the contents of copper have been reported as 2-50 µg/g DW (ppm) and the concentration suitable for shoots have been reported to be 6 $\mu g\ g^{-1}$ (Epstein and Bloom 2005). The levels of copper below 5 µg/g DW in vegetative tissues were known to show its deficiency while levels above 20 µg/g DW showed toxic effects (Marschner 1995, Burkhead *et al.* 2009).

As a crucial micronutrient, copper accelerated the growth of *Vigna radiata* seedlings at low concentrations while high concentration of copper caused growth retardation as it interfered with normal cellular metabolic processes (Alia *et al.* 1995).The copper content in potato tubers was found to be 6.145 - 6.274 mg/kg dry matter, being significantly affected by a cultivar, weed control method, including herbicides and the weather conditions during the growing season (Zarzecka*et al.* 2016). Micronutrients like Zn, Cu, Mn, B and Mo have been reported to enhance the contents of ascorbic acid in tubers (Grewal and Trehan 1979). Gupta and Prasad (1989) conducted field experiments involving soil application and foliar spray of copper (as sulphate) at Jharnapani farm of the North-Eastern hill research complex, Nagaland. It was revealed that spray and basal application viz. 2.0 kg + 5.0 kg copper sulphate/ha resulted in maximum yield and profitability. Dwivedi and Dwivedi (1991) found that micronutrients application in potato through different methods such as basal, foliar or seed treatment was found to be equally effective. Trehan and Grewal (1995) found that potato tuber yield was reported to be higher when copper sulphate ($CuSO_4$) was applied in soil and foliar. Moreover, it was further emphasized that foliar spray of copper was much effective when compared to soil amendment. Romemheld and El-Fouly (1999) deduced that nutrient treatment through spray were proficient medium to enhance the performance of crops.

Agarwal *et al.* (2004) revealed that the copper application (5%) via drip irrigation increased the uptake of macro and micronutrients like nitrogen, phosphorus, potassium, zinc, iron and copper. According to Wierzbicka and Trawczynski (2011), potato varieties too influenced the contents of copper in potato tubers.

Foliar application of micronutrients (Zn, Cu, Zn + Cu + Mo) was used as an effective mode in reducing the chances of late blight from 65.4 % to 92.6 % and also proved to be equally beneficial in increasing tuber yield from 36.3 to 45.9 % (CPRI 2008).A significant increase in tuber yield (444 q/ha) and net return was reported under application of micronutrients (Fe, Mn, Zn, Cu and B) at 40, 50 and 60 days after planting. In Jalandhar region (Punjab), a field experiment was done to find the effects of basal and foliar spray of Zn, Cu and Fe. The results revealed that foliar spray of copper sulphate and zinc sulphate led to enhanced tuber yield in regions infected by late blight. Moreover, it was found that copper dramatically reduced the intensity of disease at all studied locations whereas zinc reduced infestation at only two locations and iron remained unaffected at any location (Trehan and Grewal 1991-92, Trehan *et al.* 1994). Sasani *et al.* (2006) observed that basal treatment of micronutrients significantly increased the potato tuber yield.

An earlier study reported that use of lower levels of copper sulfate pentahydrate along with chitosan sticker and complexing agent acted as promising strategy for disease control. However, in excised leaf assays, copper hydroxide when applied at concentration 40 fold lower than recommended dose, proved to control cases of blight to a moderate extent and also provided protection against copper-related leaf yellowing (Hadwiger and McBride 2006).

Sharma and Grewal (1988) conducted field experiment during 1978-79 and 1979-80 to study the effectiveness of various methods of micronutrient application on potato variety Kufri Chandramukhi. During both the years, pre-soaking of seed tubers in $ZnSO_4$ solution (0.05%) for 3 hours followed by foliar application of zinc (0.2%) as $ZnSO_4$ at 40 and 60 DAP led to significantly increased tuber yield. Foliar application of manganese sulphate (0.2% $MnSO_4$ solution) and copper sulphate solution (0.05%) led to dramatic increase in the tuber yield in contrast to control. No such marked variation in yield was observed under iron application.

Gupta and Prasad (1989) conducted field experiments involving soil application and foliar spray of copper (as sulphate) at Jharnapani farm of the North-Eastern Hill Research Complex, Nagaland. Maximum yield and profitability were recorded with spray and basal application of 2.0 kg and 5.0 kg copper sulphate/ha, respectively.

2.2.4 Soil and plant analytical parameters

The copper uptake in plants depends upon number of things such as pH of soil, presence of chemical species and levels of Cu in soil. Copper is thinly immobile once it is inside the plant (Barker and Pilbeam 2007). Also, it is reported that rate of uptake of Cu in plants was found to lowest as compared to all essential elements under investigation (Kabata - Pendias and Pendias 1992). The copper uptake in roots of plant is adynamic method and depends upon copper species. It is readily available at or below pH 6.0 (Adriano 2001). The research conducted by Mystkowska and Matyszczak (2019) depicted that the experimental potato varieties varied in contents of copper. The mean content of copper in potato tubers were reported in the range of 3.2 - 3.7 mg kg^{-1}DM and absolutely depended upon the varieties. Honorata variety possessed maximum elemental content while lowest was observed in the Tajfun variety. The Jelly variety exhibited highest ability for copper uptake (41.2 g·/ha) along with the tuber yield while the lowest was reported (33.8 g/ha) in Honorata variety. The varietal differences between the copper content were established by Browszys *et al.* (2009), Zarzecka and Gugała (2009), Gugała and Zarzecka (2011), Wierzbowska *et al.* (2015), Zarzecka *et al.* (2016). It is reported that copper availability in soils decreased at pH above 7.0. Increased pH of soil led copper to bind more tightly to soil components. It was also stated that nutrient solutions deficient in Fe and P stimulated copper uptake and abundant supplies of phosphorus decreased copper accumulation (Xiong *et al.* 2002). In plants, the contents of copper ranged from 0.08 to 0.24 mmol/g dry weight and toxicity of copper generally occured when concentration exceeded 0.4 mmol/g dry weight (Macnicol and Beckett 1985). Foliar damage and yield loss from Zn and Cu toxicity can occur from over application of foliar sprays or from concentrating too much in fertilizer (Hoskins, 2012). The adequate content of copper in potatoes was reported to be 20 mg per kg dry matter (Kabat-Pendias and Mukherjee 2007, Wierzbicka 2012). The recommended dose of copper content was reported to be 900 $\mu g^{-1}$by Academy of Food and Nutrition Sciences (USA) (Wierzbicka 2012) and it was elucidated that of 100 grams of consumption of potatoes covered nearly 11% of the daily requirement of copper intake.

In a recent study by Gąsiorowska *et al.* 2018, FYM and under sown catch crops i.e. plants of *Fabaceae* family preceding the cultivation of potato led to considerable decrease in the copper content of potato tubers. Likewise, use of manure and compost resulted in decline in the copper content of potato tuber (Musilova *et al.* 2016, Garrido *et al.* 2017). The concentration of the elements was reported to be minimum in tubers grown organically (4390 mg /kg) in contrast to the integrated system (4609 mg /kg) (Hajslova *et al.* 2005, Wang *et al.* 2008, Hunter *et al.*2011).

The tuber mineral contents varied among different cultivable potato cultivars. A study found that the cultivation of potato crop under similar conditions led to differences in concentrations of macro and micro-elements in tuber (Tekalign and Hammes 2005, White *et al.* 2009). The concentration of potassium, magnesium, iron, zinc, manganese and copper in tuber was reported to be significantly different in marketable potato genotypes (Rivero *et al.* 2003, Di Giacomo *et al.* 2007). However, the mineral element distribution was found to vary within potato tubers. The differences in the concentration of mineral contents were found in stem ending and distal ends of potato tubers, with more concentrated mineral nutrients found in the skin of potato tubers as compared to the tissue (Karenlampi and White 2009).

2.2.5 Economics

Application of Grow More Nutrition (containing copper as constituent) in an experiment by Flieh *et al.* 2019 found a significant improvement in yield parameters and economics cultivation of potato plants. Data related to the economics of potato yield cultivation depicted a maximum gross return (12,576,000 Din/ha) in treatment T_3 (50 mg/L), followed by T_2 (25 mg/L) (9,648,000 Din/ha). The minimum return (6,880000 Dinnar (Din)/ha) was obtained in treatment T_1control. Maximum net return (9,408,000 Din/ha) was recorded in treatment T_3 (50 mg/L), followed by treatment T_2 (25 mg/L) (6,492,000 Din/ha) while the control treatment produced only (3,736,000 Din/ha). Maximum cost benefit ratio (3.96) was recorded in treatment T3 (50 mg/L), followed by treatment T_2 (25 mg/L) (3.05) while it was only (2.18) in control. It was further supported by other researchers (Kumar *et al.* 2007, Kashyap *et al.* 2022).

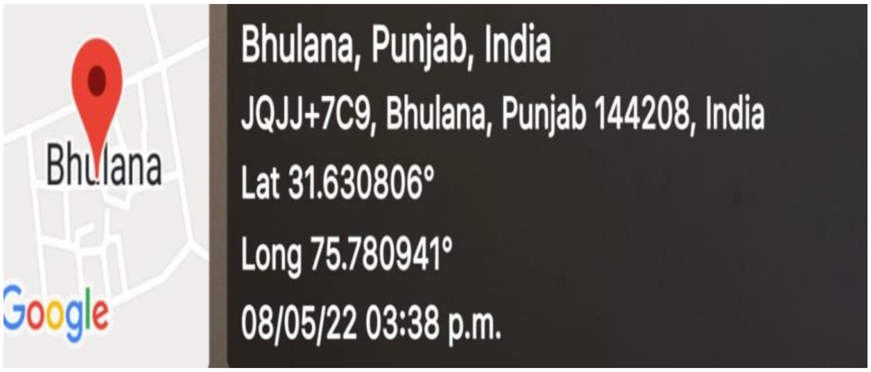
Chapter 3
Materials and methods

The field trial of current investigation entitled, 'Effect of potassium and copper on yield and quality of potato (*Solanum tuberosum* L.) in a Typic Ustorthent soil in sub - mountain area of Punjab' was conducted during *Rabi* seasons of 2017-18 and 2018-19 at village Bhulana, Hoshiarpur (Punjab). The detailed information regarding materials used and the procedure engaged in the study are explained in this chapter.

3.1 General description of study area

3.1.1 Location

The research area was located at 31º63' N latitude, 75º78' E longitude at an altitude of 299 m above MSL (mean sea level).



3.1.2 Rainfall and climate

The climate of Hoshiarpur is comparatively cool and humid owing to its proximity to the hills. The meteorological data based on monthly interval depicting minimum and maximum temperature, relative humidity, rainfall throughout the cropping season are put forward in table 3.1 and 3.2.Scrutiny of figures depicted that the average rainfall in 2017-18 was 14.2 mm and during the year 2018-19, it was reported to be 49.3 mm. The average monthly temperature varied from 6.2 ºC to 35.8ºC and the mean relative humidity varied from 27 % to 94 % during the crop growing season of 2017-18. In the next cropping season 2018-19, the mean monthly temperature ranged from 6.1 ºC to 35.6ºC and the mean relative humidity varied from 29.5 % to 94 %.

Table 3.1 Agro-meteorological data on monthly basis from September 2017- April 2018

Months	Temp. (°C)		RH (%)		Average Rainfall (mm)
	Max.	Min	Morning	Evening	
September	33.7	24	87	56	25.4
October	33.2	18.7	89	39	0
November	24.7	11.5	92.9	47	7
December	20.9	7.7	91	47	24
January	18.7	6.2	94	56	18.4
February	22.8	9.1	89	45	27
March	29.3	13.8	85	39	0
April	35.8	19.9	60	27	14.8

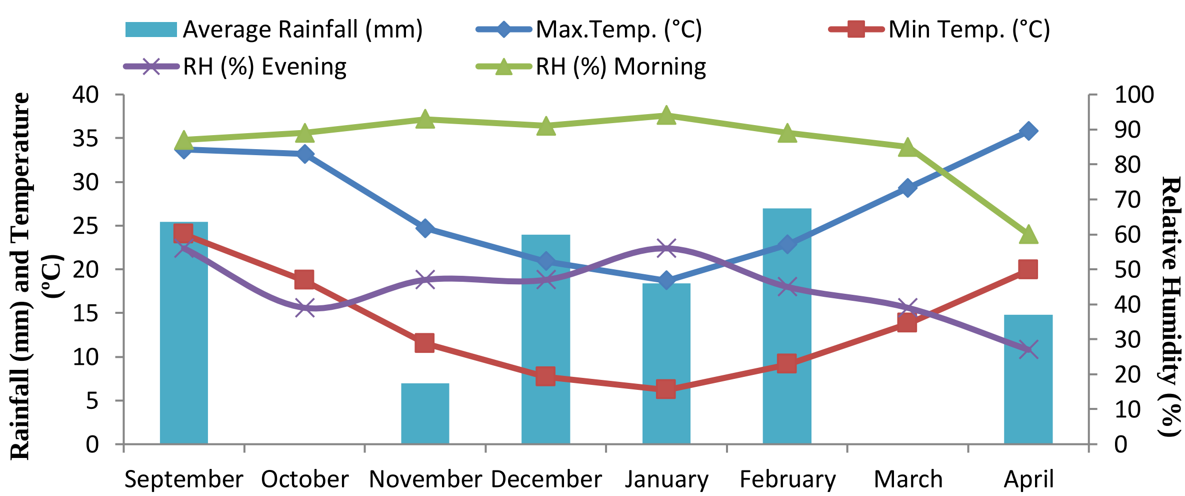


Fig. 3.1 Agro-meteorological data on monthly basis from September 2017- April 2018

Table 3.2 Agro-meteorological data on monthly basis from September 2018- April 2019

Months	Temp. (ºC)		RH (%)		Average Rainfall (mm)
	Max.	Min	Morning	Evening	
September	32.1	23.9	88	63	250.7
October	31.3	17.2	89	39	0
November	26.8	11.8	89.8	36	2.6
December	20.7	5.8	94	43	0
January	18.5	6.1	91.7	49.6	30.3
February	19.9	9.1	91.4	57.8	34.4
March	25.0	11.8	88.7	45.4	27.3
April	35.6	19.5	70.8	29.5	6

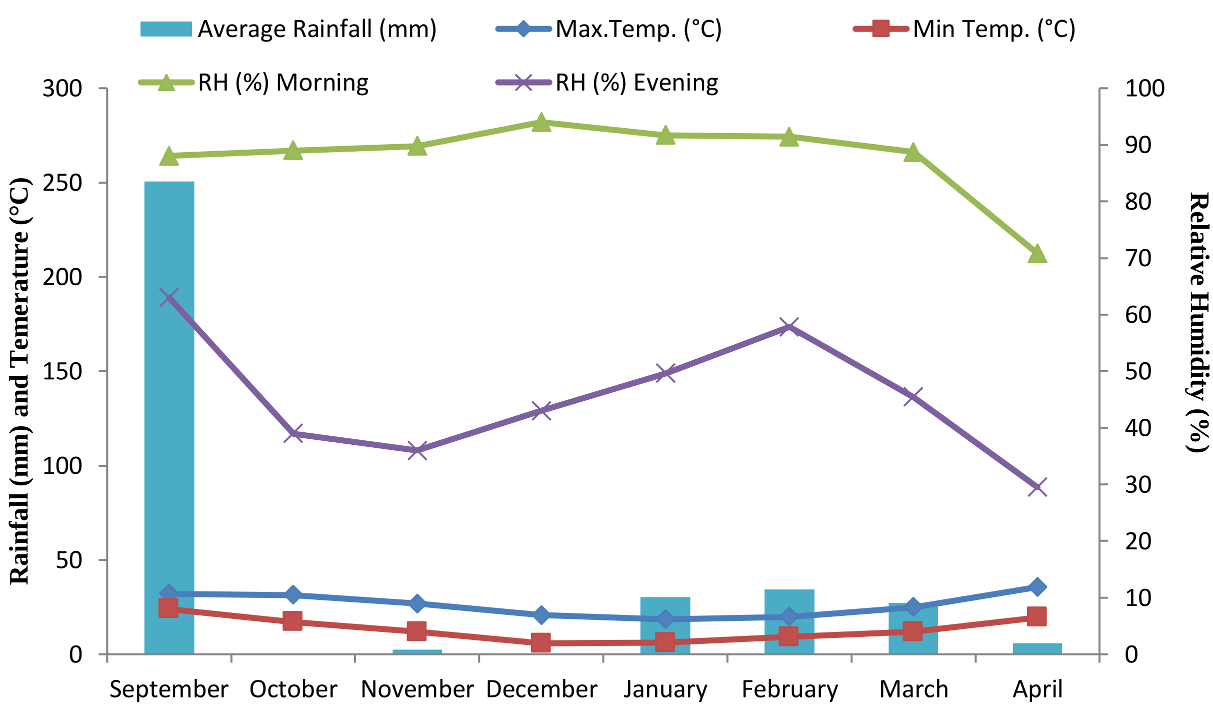


Fig. 3.2 Agro-meteorological data on monthly basis from September 2018- April 2019

3.1.3 Physical and chemical properties of soil

The physical and chemical properties that were studied are mentioned below:

Contents	Range	Method
Sand (%) Silt (%) Clay (%) Texture class	82.20 10.84 6.36 Loamy sand	International pipette method as given by Piper (1966)
Chemical properties		
pH	Normal (7.9)	1:2.5 soil:water suspension by using glass electrode pH meter as per method of Jackson(1967)
Available Nitrogen (kg ha^{-1})	158.83	Alkaline permanganate method given by Subbiah and Asija(1956)
Available Phosphorus (kg ha^{-1})	13.3	Olsen's method as per Olsen *et al.*1954
Available Potassium (kg ha^{-1})	180.8	Normal neutral ammonium acetate method by Merwin and Peech (1951)
Copper (mg/kg)	0.5	Cate and Nelson (1971)

3.2 Experimental details:

3.2.1Treatment details:

Following treatments were incorporated during the study:

S.No.	Treatments*
T_1	Control
T_2	100% K_2O (RDF)
T_3	75% K_2O (RDF)
T_4	125% K_2O (RDF)
T_5	K_2O (75%) + Cu (75%) Foliar application

T_6	K_2O (75%) + Cu (100%) Foliar application
T_7	K_2O (75%) + Cu (125%) Foliar application
T_8	K_2O (100%) + Cu (75%) Foliar application
T_9	K_2O (100%) + Cu (100%) Foliar application
T_{10}	K_2O (100%) + Cu (125%) Foliar application
T_{11}	K_2O (125%) + Cu (75%) Foliar application
T_{12}	K_2O (125%) + Cu (100%) Foliar application
T_{13}	K_2O (125%) + Cu (125%) Foliar application
T_{14}	Control + Cu Foliar application

* Recommended dose of fertilizer (RDF) = N @ 187 kg/ha, P_2O_5 @ 62 kg/ha, K_2O @ 62 kg/ha (Anonymous, 2021). N and P doses are same in all the treatments. RDF of $CuSO_4$ = 200g/100L of water (CPRI, 2008)

Design: RBD

Treatment combinations: 14

Replication: 3

Spacing: 60×20 cm

Plots: 42

Plot size: 7×3 m^2

Path

Irrigation channel

R_1	T_9	T_8	T_7	T_6	T_5	T_4	T_3	T_2	T_1	T_{11}	T_{12}	T_{13}	T_{14}	T_{10}

Irrigation channel

R_2	T_5	T_{11}	T_8	T_2	T_{14}	T_{10}	T_6	T_{12}	T_7	T_{13}	T_4	T_9	T_3	T_1

Irrigation channel

R_3	T_{14}	T_2	T_{10}	T_1	T_6	T_3	T_9	T_4	T_{11}	T_7	T_5	T_{12}	T_{13}	T_8

Fig. 3.3 Layout plan of the experiment

Plate 1. Sowing of the crop **Plate 2. Emergence of the crop**

Plate 3: Foliar Application on the crop **Plate 4: Earthing-up of the crop**

3.3 Observations

3.3.1 Crop studies

3.3.1.1 Growth studies

a. Emergence percentage at 15 days (%): Before the emergence of crop, 1m row length area was marked arbitrarily at two locations in each one plot and the emergence of plants was noted on regular basis until steady count was obtained. The ultimate observation of two sampling sites was collected, mean was calculated for emergence count/m^2 and emergence percentage was then calculated.

b. Plant height at monthly interval and at harvest (cm): Five potato plants were selected arbitrarily from the plot area to note the plant height at the monthly interval after sowing and at the time of harvest. The height was measured in centimeters and reading was recorded starting from the base to the highest leaf tip via a meter scale. The standard height of plant was found and was expressed in cm.

c. Fresh weight and dry weight (g/plant): For calculating fresh weight, the plant samples were taken and weighed. To calculate dry weight, plant samples were dried under sunlight followed by drying at 70^0C in hot air oven until invariable weight was obtained and data was then presented as g/plant.

d. Leaf area index at monthly interval: From randomly selected five plants, five leaves were taken randomly and mean LAI was calculated using digital leaf area meter. The total LAI was then calculated by following formula:

$$\text{LAI} = \frac{\text{Leaf area m}^2}{\text{Land area m}^2}$$

e. No. of haulms per plant: Five plants were chosen arbitrarily and total no. of haulms were counted. Thereafter, mean number of haulms plant^{-1} was calculated.

3.3.1.2 Development studies

i. Days to emergence

The emergence count was recorded daily from the earmarked three metre row length in each net plot from the date of first emergence of seedling till it was constant. The numbers of days taken to emergence was counted from the date of sowing.

ii. **Days to maturity**

It was measured as the number of days from sowing date to 95 per cent maturity. In potato it was assessed when the foliage dried or has died down naturally and skins have set.

3.3.1.3 Yield attributes

a. Number of plants per meter row length: Before harvesting, total number of plants present in the one meter row length was recorded and expressed as number of plants per meter row length.

b. Average number of tubers per plant: From five labeled plants, number of tubers was noted and the average no. of tubers plant^{-1} was calculated.

c. Average weight of tubers per plant (g): Five plants were randomly selected at the time of harvest and tubers from these selected plants were weighed and the mean was calculated.

d. Average weight of tuber (g): Ten tubers were preferred erratically belonging to different grades and were weighed. The mean weight of tubers was then calculated.

e. Potato tuber yield: From the net area, the crop was harvested by digging the plants with shovel. The tubers were cut off from the plants. The yield of tubers was calculated and expressed as quintals hectare^{-1}.

f. Haulm yield: The above ground plant parts collected from net plot area were separated out and dried in sun by spreading for fifteen days. The weight of these well dried haulms was taken and expressed as haulm yield in q/ha.

3.3.1.3 Quality parameters

a. Starch

Starch content was estimated by the method of anthrone prescribed by McCreddy *et al.* (1950) and expressed in percent. So as to remove the sugars, the sample was pre-treated with 80% alcohol and then treatment with perchloric acid was followed to extract starch. Under hot acidic conditions, starch gets hydrolysed to glucose and then gets dehydrated to hydroxymethyl furfural, which when made to react with anthrone reagent, yielded green coloured complex, whose absorbance maxima was read at 620 nm with spectrophotometer.

a. Grading of potato tubers

Produce from all net plots were graded into different grades based on average weight of tuber as:

Grade A	tuber weight > 75g
Grade B	tuber weight 50-75g
Grade C	tuber weight <50g

Total tubers of different grades were weighed and data was expressed in q ha^{-1}.

b. **Specific gravity(g/cm^3)**

The specific gravity was analyzed by the method described by Haque *et al.* (2018). The chosen samples were pre-weighed in air followed by re-weighing carried out by suspending in water. Specific gravity in g/cm^3 was then calculated by following formula:

$$\text{Specific gravity} = \frac{\text{Weight in air}}{(\text{Weight in air} - \text{Weight in water})}$$

c. Vitamin C

The vitamin C (ascorbic acid) content of the sample was determined by redox titration method prescribed by Ivanov and Popov (1994) and was expressed as mg/100g. Dichlorophenolindophenol (DCPIP) is a blue coloured dye in the oxidised state that is reduced to colorless solution ($DCPIPH_2$) by ascorbic acid. During the process, ascorbic acid gets oxidized to dehydro-ascorbic acid and yield light pink color in acidic medium.

3.3.1.4 Soil studies

a. Available nitrogen

Available nitrogen was determined by method described by Subbhiah and Asija (1956) using alkaline permanganate. Dried sample of soil was weighed and treated with alkaline permanganate solution followed by distillation. The organic matter present in soil was oxidized by nascent oxygen, which occured as a result of reaction between potassium permanganate in the presence of sodium hydroxide and the released ammonia was condensed and absorbed in specific volume of boric acid using mix indicator to form ammonium borate, which was then titrated with a standard sulphuric acid.

b. Available phosphorus

The available phosphorus was determined by Olsen *et al.* (1954) method. In this method, 5 cm^3 soil was extracted for 30 min with 100 cm^3 0.5 $NaHCO_3$ solution (pH – 8.5). After filtration, the phosphate concentration was measured calorimetrically and the results were expressed as mg/L of soil.

c. Available potassium

The available K was found by normal neutral ammonium acetate method (Merwin and Peech 1951). 5 g soil was weighed in a 150 ml conical flask followed by addition of 25 ml of neutral ammonium acetate solution. The contents of flask were shaken for five minutes and the obtained suspension was filtered via filter paper (Whatman No.1). Five (5) ml of the extract was then taken into 25 ml volumetric flask. After this distilled water was used for final volume makeup. The solution was then fed to the atomizer of the flame photometer and the reading was calculated.

d. Copper content

The content of copper was determined with the Atomic Absorption Spectroscopy after previous crushing, drying and mineralization of potato tuber samples in the laboratory furnance at a temperature of 450-550 °C (Cate and Nelson,1971).

3.3.1.5 Plant analysis

a. Total K content

At the time of harvest, multiple samples of tuber and haulms were collected from each net plot, processed and analyzed for determination of total K content by following standard analytical methods.

Digestion with di-acid mixture was carried out and the extract obtained was determined by flame photometer (Chapman and Brown 1950). The principle is based upon that when atoms of potassium are excited, emission of specific wavelength takes place, which is proportional to the concentration of potassium, detected in flame photometer using potassium filter. To the pre-digested sample, 5 ml of triacid mixture comprising concentrated HNO_3, concentrated H_2SO_4 and $HClO_4$ (10:1:4) was added and digestion was then carried out on a digestion mantle at 180 to 200°C until clear white residue was obtained in the flask. The mixture was left to cool and digestion was carried out in 6 N HCl (10-15 ml). The digested sample was finally put to 50 ml volumetric flask and the final volume makeup was done with distilled water.

b. Copper content

The content of copper was determined with the Atomic Absorption Spectroscopy after previous crushing, drying and mineralization of samples in the laboratory furnance at a temperature of 450-550 °C (Cate and Nelson,1971).

3.3.1.6 Harvest Index (HI): The HI was calculated by the subsequent formula:

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.3.1.7 Economic studies: The economics of different treatments were calculated by considering the cultivation cost, gross and net return hectare^{-1} and net returns rupee^{-1} invested. The existing sale price for various inputs and outputs were also considered.

a. Gross returns: The produce value was calculated based upon current sale prices in the farm area and was expressed in Rs/ha. The selling price of potato tubers was Rs. 10/ kg.

b. Net returns: Net return was calculated by subtracting the cost of cultivation from the gross returns and was expressed as Rs/ha.

c. Net returns per rupee invested: The net return per rupee invested was calculated by following formula:

$$\text{Net returns per rupee invested} = \frac{\text{Net return (Rs. ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs. ha}^{-1}\text{)}}$$

3.3.1.8 Statistical analysis: The statistics resulted from present study was subjected to the determination of analysis of variance via requisite statistical computation by following the procedure given by Gomez and Gomez (1984) to calculate the cause and effect relationship among various parameters.

Chapter-4

Results and discussion

The detailed investigation entitled ‘Effect of potassium and copper on yield and quality of potato (*Solanum tuberosum* L.) in a Typic Ustorthent soil in sub-mountain area of Punjab’ was conducted during year 2017-18 and 2018-19. The experiment was performed at village Bhulana, Hoshiarpur (Punjab).The observations on growth, biochemical and yield attributes were analyzed statistically in current study and are presented in this chapter. Each of the characteristics of potato was described with the help of tables under subsequent headlines:

4.1 Effect of different treatments on growth parameters

4.1.1 Emergence percentage

4.1.2 Effect on plant height

4.1.3 Effect on fresh and dry weight

4.1.4 Effect on leaf area index

4.1.5 Effect of different treatments on number of haulms

4.2 Effect of different treatments on development studies

4.2.1 Days to emergence

4.2.2 Days to maturity

4.3 Effect of different treatments on yield attributes and yield

4.3.1 Number of plants per square meter

4.3.2 Average number of tubers per plant

4.3.3 Average weight of tuber

4.3.4 Average weight of tubers per plant

4.3.5 Tuber yield

4.3.6 Haulm yield

4.4 Effect of different treatments on quality parameters

4.4.1 Starch content

4.4.2 Vitamin C

4.4.3 Specific gravity

4.4.5 Grading of potato tubers

4.5 Effect of different treatments on soil properties

4.5.1 Available potassium content of the soil at harvest

4.5.2 Potassium content in tuber and haulm

4.5.3 Copper content in tuber

5.1 Effect of different treatments on harvest index

Chapter-4

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4.4.2 Vitamin C

4.4.3 Specific gravity

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4.5.2 Potassium content in tuber and haulm

4.5.3 Copper content in tuber

5.1 Effect of different treatments on harvest index

6.1 Effect of different treatments on economic studies

6.1.1 Gross returns

6.1.2 Net returns

6.1.3 Net returns per rupee invested and B:C ratio

4.1 Effect of different treatments on growth parameters

4.1.1 Emergence percentage

The emergence percentage was recorded during two years (2017-18, 2018-19). The data revealed that application of potassium, copper and their combination posed non-significant effect on the emergence percentage during 1st and 2nd year. Effect of treatments on the emergence percentage has been shown in table 4.1. In the 1st and 2nd year, the average emergence percentage was recorded to be 95.5%, which clearly depicted negligible effect of fertilizer dose on the potato emergence. The results are according to previous findings of Krishnappa (1990), who observed that the emergence of seed tubers were 92 to 96% under different treatments, revealing that fertilizers have no effect on emergence of seed tubers (Noor *et al.* 2011, Ayyub *et al.* 2011).

Table 4.1 Effect of different treatments on emergence of potato

Treatments*		Emergence (%)		
		Ist year (2017-18)	2nd year (2018-19)	Mean
T_1	Control	95.40	95.00	95.20
T_2	100% K_2O (RDF)	96.20	96.00	96.10
T_3	75% K_2O (RDF)	95.27	95.80	95.53
T_4	125% K_2O (RDF)	96.10	96.00	96.05
T_5	K_2O (75%) + Cu (75%) Foliar application	95.00	95.10	95.05
T_6	K_2O (75%) + Cu (100%) Foliar application	95.23	95.40	95.32
T_7	K_2O (75%) + Cu (125%) Foliar application	95.00	95.43	95.22
T_8	K_2O (100%) + Cu (75%) Foliar application	95.83	95.57	95.70
T_9	K_2O (100%) + Cu (100%) Foliar application	95.27	95.00	95.13
T_{10}	K_2O (100%) + Cu (125%) Foliar application	95.70	95.93	95.82
T_{11}	K_2O (125%) + Cu (75%) Foliar application	95.90	96.00	95.95
T_{12}	K_2O (125%) + Cu (100%) Foliar application	95.97	96.10	96.03
T_{13}	K_2O (125%) + Cu (125%) Foliar application	96.00	95.70	95.85
T_{14}	Control + Cu Foliar application	95.10	94.90	95.00
	CD	NS	NS	NS

* RDF = N@187kgha^{-1}, P_2O_5@62 kgha^{-1}, K_2O@62 kgha^{-1}. N and P doses were same in all the treatments

4.1.2 Effect on plant height

The data obtained in the table 4.2 showed a variable increase in the plant height. The application of potassium, copper and its combination at 30 DAS recorded the maximum plant height under the treatment T_{13} (30.60cm in 2017, 32.00 cm in 2018 and 31.30 cm in the mean data of both the years) over the control treatment T_1 with the plant height of 18.00 cm during 2017, 19.00 cm during 2018 and 18.50cm in the mean data of both the years. The percent increase recorded in T_{13} over the control T_1 was 12 % in 2017, 13 % in 2018 and 12.8% in average. The treatment T_{13} was followed by the treatment T_{12} (29.90 cm in 2017, 31.00 cm in 2018 and 30.45 cm in the mean data) and results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} as considerable increase in the plant height was recorded (28.80 cm during 2017, 30.50 cm during 2018 and 29.65 cm in the mean data) over the control treatment T_1 which is evident from table 4.2.

Table 4.2 Effect of different treatments on plant height at 30 days of sowing (DAS)

Treatments*		Plant height at 30 DAS		
		I^st year (2017-18)	2^nd year (2018-19)	Mean
T_1	Control	18.00	19.00	18.50
T_2	100% K_2O (RDF)	26.00	28.00	27.00
T_3	75% K_2O (RDF)	19.20	20.60	19.90
T_4	125% K_2O (RDF)	28.20	30.10	29.15
T_5	K_2O (75%) + Cu (75%) Foliar application	19.90	20.40	20.15
T_6	K_2O (75%) + Cu (100%) Foliar application	20.80	21.60	21.20
T_7	K_2O (75%) + Cu (125%) Foliar application	22.00	23.00	22.50
T_8	K_2O (100%) + Cu (75%) Foliar application	26.20	28.50	27.35
T_9	K_2O (100%) + Cu (100%) Foliar application	27.40	29.40	28.40
T_{10}	K_2O (100%) + Cu (125%) Foliar application	28.00	30.00	29.00
T_{11}	K_2O (125%) + Cu (75%) Foliar application	28.80	30.50	29.65
T_{12}	K_2O (125%) + Cu (100%) Foliar application	29.90	31.00	30.45
T_{13}	K_2O (125%) + Cu (125%) Foliar application	30.60	32.00	31.30
T_{14}	Control + Cu Foliar application	18.50	19.80	19.15
	CD	1.62	1.12	1.08

* RDF = N@187kgha^{-1}, P_2O_5 @62 kgha^{-1}, K_2O@62 kgha^{-1}. N and P doses were same in all the treatments.

Similar increase in the plant height was observed at 60 and 90 DAS as shown in table 4.3 and 4.4. At 60 DAS, maximum plant height was observed in treatment T_{13} (50 cm in 2017, 52.00 and 51.00 cm in the mean data of both the years) over the control treatment T_1 with the plant height of 25.80 cm during 2017, 28.00 cm during 2018 and 26.90 cm in the mean data of both the years. The percent increase recorded in T_{13} over the control T_1 was 24.2 % in 2017, 24 % in 2018 and 24 % in the pooled data. The treatment T_{13} was followed by the treatment T_{12} (49.00 cm in 2017, 51.00 cm in 2018 and 50.00 cm in the mean data) and results remained at par with T_{13}. Similarly, the treatment T_{11} followed $T_{12}$where plant height was recorded as (48.20 cm during 2017, 50.80 cm during 2018 and 49.50 cm in the mean data) over the control treatment T_1 which is evident from table 4.3.

Table 4.3 Effect of different treatments on plant height at 60 days of sowing (DAS)

Treatments*		Plant height at 60 DAS		
		Ist year (2017-18)	2nd year (2018-19)	Mean
T_1	Control	25.80	28.00	26.90
T_2	100% K_2O (RDF)	45.00	47.00	46.00
T_3	75% K_2O (RDF)	40.80	42.00	41.40
T_4	125% K_2O (RDF)	48.00	50.00	49.00
T_5	K_2O (75%) + Cu (75%) Foliar application	41.20	43.00	42.10
T_6	K_2O (75%) + Cu (100%) Foliar application	41.20	43.90	42.55
T_7	K_2O (75%) + Cu (125%) Foliar application	42.50	45.00	43.75
T_8	K_2O (100%) + Cu (75%) Foliar application	43.80	47.40	45.60
T_9	K_2O (100%) + Cu (100%) Foliar application	45.00	49.00	47.00
T_{10}	K_2O (100%) + Cu (125%) Foliar application	46.00	49.80	47.90
T_{11}	K_2O (125%) + Cu (75%) Foliar application	48.20	50.80	49.50
T_{12}	K_2O (125%) + Cu (100%) Foliar application	49.00	51.00	50.00
T_{13}	K_2O (125%) + Cu (125%) Foliar application	50.00	52.00	51.00
T_{14}	Control + Cu Foliar application	26.50	29.00	27.75
	CD	3.05	2.75	1.89

* RDF = N@187kgha^{-1}, P_2O_5 @62 kgha^{-1}, K_2O@62 kgha^{-1}. N and P doses were same in all the treatments.

Likewise, at 90 DAS, maximum plant height was observed in treatment T_{13} (59 cm in 2017, 62.00 and 60.50 cm in the mean data of both the years) over the control treatment T_1 with the plant height of 33.8 cm during 2017, 35.00 cm during 2018 and 34.40 cm in the mean data of both the years. The percent increase recorded in T_{13} over the control T_1 was 25.2 % in 2017, 27 % in 2018 and 26 % in the mean data. The treatment T_{13} was followed by the treatment T_{12} (58.20 cm in 2017, 61.00 cm in 2018 and 59.60 cm in the mean data) and results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12}in which a considerable increase in the plant height was recorded (57.50 cm during 2017, 60.50 cm during 2018 and 59.00 cm in the mean data) over the control treatment T_1 which is evident from table 4.4. Among 30, 60 and 90 DAS, maximum height was observed at 90 DAS under treatment $T_{13.}$

Table 4.4 Effect of different treatments on plant height at 90 days of sowing (DAS)

Treatments*		Plant height at 90 DAS		
		Istyear (2017-18)	2nd year (2018-19)	Mean
T_1	Control	33.80	35.00	34.40
T_2	100% K_2O (RDF)	55.00	57.00	56.00
T_3	75% K_2O (RDF)	52.00	55.00	53.50
T_4	125% K_2O (RDF)	57.00	60.00	58.50
T_5	K_2O (75%) + Cu (75%) Foliar application	52.50	55.80	54.15
T_6	K_2O (75%) + Cu (100%) Foliar application	53.20	56.40	54.80
T_7	K_2O (75%) + Cu (125%) Foliar application	54.80	57.00	55.90
T_8	K_2O (100%) + Cu (75%) Foliar application	55.50	57.80	56.65
T_9	K_2O (100%) + Cu (100%) Foliar application	56.00	58.60	57.30
T_{10}	K_2O (100%) + Cu (125%) Foliar application	56.80	59.40	58.10
T_{11}	K_2O (125%) + Cu (75%) Foliar application	57.50	60.50	59.00
T_{12}	K_2O (125%) + Cu (100%) Foliar application	58.20	61.00	59.60
T_{13}	K_2O (125%) + Cu (125%) Foliar application	59.00	62.00	60.50
T_{14}	Control + Cu Foliar application	34.50	36.00	35.25
	CD	1.70	2.62	1.98

* RDF = N@187kgha^{-1}, P_2O_5 @62 kgha^{-1}, K_2O@62 kgha^{-1}. N and P doses were same in all the treatments.

These results were found to be consistent with study conducted by Khandakhar *et al.* (2004), where potassium application increased the plant height from 45.29 cm to 54.76 cm at 60 days after planting. Likewise, Al-Moshileh and Errebi (2007) found that potassium levels affected plant height of potato and the maximum plant height (46.33 cm) was recorded under application of potassium sulphate (K_2SO_4) @ 450 kg/ha. In earlier studies conducted by Noor (2010), it was found that K_2O application in the range 100-150 kg K_2Oha^{-1} increased the uptake of N in plants, resulting in maximum plant height. Plant height increased gradually and significantly during high levels of potassium application @285 kg K_2O/ha (Asmaa and Magda (2010). Furthermore, significant variation at $p < 0.001$were observed in different potato varieties on the basis of plant height. The studied potato cultivar i.e Ajiba was reported to attain highest plant height (42.15 cm) while minimum (32.48 cm) was obtained in Picasso. The differences occurred in the growth characters due to the genetic make-up of the crop (Enujeke 2013).

The outcomes of the current investigation were according to the results of Asmaa and Hafez (2010) where potassium application resulted in higher plant height in potato. Potassium contributes toward increased cell division and elongation, thus resulting in higher canopy development. This was further supported by Marschner (1995) where potassium resulted in enhanced cellular growth and development. Likewise, Khandakhar *et al.* (2004) found that potassium treatment led to maximum plant height. Copper influences carbohydrate and protein metabolism as it acts as chief constituent of enzymes and serves as a catalyst in photosynthesis and respiration. The consistent increase in the plant height with the increasing potassium and copper (125%) application depicts the requirement of these nutrients to promote the uptake of other macro-nutrients i.e. nitrogen and phosphorus from soil that promoted growth and development via activation of enzymes mediating cell mitosis, division, ultimately resulting in elongation as compared to other treatments (Sati *et al.* 2017).

4.1.3 Effect on Fresh and Dry weight of plant

A perusal of data shown in Table 4.5 and 4.6 depicts a variable increase in the fresh and dry biomass. The treatment combination of potassium and copper after sowing recorded the maximum fresh weight (g/plant) under the treatment T_{13} (179 g in 2017, 188.67 g in 2018 and 182.33 g in the mean data of both the years) over the control treatment T_1 with the fresh weight of 160.33 g during 2017, 165.00 g during 2018 and 162.25 g in the pooled data of both the years. The percent increase recorded in T_{13} over the control T_1 was 18 % in 2017, 23 % in 2018 and 20 % in the mean data. The treatment T_{13} was followed by the treatment T_{12} (178 g in 2017, 187.33 g in 2018 and 180.67 g in the mean data) and results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} as significant increase in the fresh weight was recorded (177 g during 2017, 185.33 during 2018 and 178.83 g in the mean data) over the control treatment T_1 which is evident from table 4.5.

Table 4.5 Effect of different treatments on fresh weight of plant

Treatments*		Fresh weight (g/plant)		
		Ist year (2017-18)	2^{nd} year (2018-19)	Mean
T_1	Control	160.33	165.00	162.25
T_2	100% K_2O (RDF)	171.33	178.00	173.17
T_3	75% K_2O (RDF)	164.50	173.00	167.25
T_4	125% K_2O (RDF)	176.00	184.00	176.67
T_5	K_2O (75%) + Cu (75%) Foliar application	165.00	175.00	167.67
T_6	K_2O (75%) + Cu (100%) Foliar application	166.67	176.67	169.50
T_7	K_2O (75%) + Cu (125%) Foliar application	168.00	177.83	171.33
T_8	K_2O (100%) + Cu (75%) Foliar application	172.67	179.33	174.67
T_9	K_2O (100%) + Cu (100%) Foliar application	174.00	180.67	175.42
T_{10}	K_2O (100%) + Cu (125%) Foliar application	175.67	183.17	176.35
T_{11}	K_2O (125%) + Cu (75%) Foliar application	177.00	185.33	178.83
T_{12}	K_2O (125%) + Cu (100%) Foliar application	178.00	187.33	180.67
T_{13}	K_2O (125%) + Cu (125%) Foliar application	179.00	188.67	182.33
T_{14}	Control + Cu Foliar application	162.33	168.33	164.67
	CD	4.55	6.01	3.10

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

Similarly, the maximum dry weight (g/plant) was observed under the treatment T_{13} (34.83 g in 2017, 35.67 g in 2018 and 33.00 g in the pooled data of both the years) over the control treatment T_1 with the fresh weight of 23.5g during 2017, 24.00 g during 2018 and 24.38g in the mean data of both the years. The percent increase recorded in T_{13} over the control T_1 was 11 % in 2017, 11 % in 2018 and 8 % in the mean data. The treatment T_{13} was followed by the treatment T_{12} (34 g in 2017, 34.77 g in 2018 and 32.80 g in the mean data) and results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} as significant increase in the fresh weight was recorded (33 g during 2017, 34 g during 2018 and 32.35 g in the mean data) over the control treatment T_1 which is evident from Table 4.6. Abd El-Baky *et al.* (2010) found similar results of increased biomass of plant with increasing dose of potassium fertilizer in sweet potato.

Table 4.6 Effect of different treatments on dry weight of plant

Treatments*		Dry weight (g/plant)		
		Ist year (2017-18)	2nd year (2018-19)	Mean
T_1	Control	23.50	24.00	24.38
T_2	100% K_2O (RDF)	30.80	31.50	30.50
T_3	75% K_2O (RDF)	28.00	29.00	29.83
T_4	125% K_2O (RDF)	32.83	33.50	31.38
T_5	K_2O (75%) + Cu (75%) Foliar application	28.67	29.50	30.50
T_6	K_2O (75%) + Cu (100%) Foliar application	29.47	30.60	30.73
T_7	K_2O (75%) + Cu (125%) Foliar application	30.50	31.50	30.88
T_8	K_2O (100%) + Cu (75%) Foliar application	31.40	32.00	31.20
T_9	K_2O (100%) + Cu (100%) Foliar application	32.00	33.00	31.63
T_{10}	K_2O (100%) + Cu (125%) Foliar application	32.80	33.47	31.77
T_{11}	K_2O (125%) + Cu (75%) Foliar application	33.00	34.00	32.35
T_{12}	K_2O (125%) + Cu (100%) Foliar application	34.00	34.77	32.80
T_{13}	K_2O (125%) + Cu (125%) Foliar application	34.83	35.67	33.00
T_{14}	Control + Cu Foliar application	24.67	26.00	16.33
	CD	1.49	2.54	2.41

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

The observed increased biomass might be as a result of increased radiation interception (over the complete season) or due to high light use efficiency, thus increasing canopy growth and water conductance of the plants, enhancing the photo assimilation and ultimately resulting in of dry matter production. It may also be due to the reason that the plants supplied with potassium and copper fertilizers either in split or combined with foliar application was presumably associated with the higher availability and uptakes of nutrients compared to control plants, which ultimately caused increased rate of crop growth with higher levels of nutrients, eventually resulting in higher dry weight. The results were further supported by Ali and Anjum (2004), Jimerez *et al.* (2011), Cuchiara *et al.*(2015), Perreault *et al.*(2016) and Sarkar *et al.* (2007) where increased applications of potassium and copper resulted in high dry matter production in plants.

4.1.4 Effect on Leaf Area Index (LAI)

A perusal of data regarding LAI index of potato at monthly interval and at harvest under different treatments have been presented in tables 4.7, 4.8 and 4.9. It was found that advancement in growing season led to increased LAI with maximum observations reported at 60 DAS that decreased marginally at harvest under all the treatments.

Table 4.7 Effect of different treatments on leaf area index at 30 days of sowing

Treatments*		Leaf area index at 30DAS		
		Istyear (2017-18)	2nd year (2018-19)	Mean
T_1	Control	1.03	1.07	1.05
T_2	100% K_2O (RDF)	1.87	2.00	1.93
T_3	75% K_2O (RDF)	1.53	1.67	1.60
T_4	125% K_2O (RDF)	1.97	2.13	2.05
T_5	K_2O (75%) + Cu (75%) Foliar application	1.55	1.69	1.62
T_6	K_2O (75%) + Cu (100%) Foliar application	1.59	1.71	1.65
T_7	K_2O (75%) + Cu (125%) Foliar application	1.65	1.75	1.70
T_8	K_2O (100%) + Cu (75%) Foliar application	1.90	2.07	1.98
T_9	K_2O (100%) + Cu (100%) Foliar application	1.95	2.10	2.03
T_{10}	K_2O (100%) + Cu (125%) Foliar application	2.00	2.15	2.08
T_{11}	K_2O (125%) + Cu (75%) Foliar application	2.05	2.20	2.13
T_{12}	K_2O (125%) + Cu (100%) Foliar application	2.07	2.23	2.15
T_{13}	K_2O (125%) + Cu (125%) Foliar application	2.10	2.27	2.18
T_{14}	Control + Cu Foliar application	1.00	1.10	1.05
	CD	0.39	0.31	0.25

* RDF = N@187kgha^{-1}, P_2O_5 @62 kgha^{-1}, K_2O@62 kgha^{-1}. N and P doses were same in all the treatments.

The application of potassium, copper and its combination at 30 DAS recorded the maximum leaf area index under the treatment T_{13} (2.10 in 2017, 2.27in 2018 and 2.18 in the mean data of both the years) in contrast to control T_1 with the LAI of 1.03 during 2017, 1.07 during 2018 and 1.05 in the mean data of both the studied years. The fold increase recorded under T_{13}as compared to control T_1 was 2.03 fold in 2017, 2.12 fold in 2018 and 2.07 fold in the mean data. The treatment T_{13} was followed by the treatment T_{12} (2.07 in 2017, 2.23 in 2018 and 2.15 in the mean data) and results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} as it possessed similar increase in the leaf area index as (2.05 during 2017, 2.20 during 2018 and 2.13 in the mean data) over the control treatment T_1 which is evident from table 4.7.

Similarly, at 60 DAS maximum leaf area index under the treatment T_{13} (2.80 in 2017, 2.97 in 2018 and 2.88 in the mean data of both the years) than control treatment T_1 with the LAI of 1.33 during 2017, 1.50 during 2018 and 1.42 in the mean data of both the years. The increase was recorded as 2.1 fold in 2017, 1.98 fold in 2018 and 2.02 fold under T_{13}in comparison to control T_1. The treatment T_{13} was followed by the treatment T_{12} (2.07 in 2017, 2.23 in 2018 and 2.15 in the mean data) and results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} where further enhancement in the leaf area index was observed (2.05 during 2017, 2.20 during 2018 and 2.13 in the mean data) over the control treatment T_1 which is evident from table 4.8.

Table 4.8 Effect of different treatments on leaf area index at 60 days of sowing

Treatments*		Leaf area index 60DAS		
		I^{st}year (2017-18)	2^{nd} year (2018-19)	Mean
T_1	Control	1.33	1.50	1.42
T_2	100% K_2O (RDF)	2.57	2.73	2.65
T_3	75% K_2O (RDF)	2.50	2.63	2.57
T_4	125% K_2O (RDF)	2.65	2.80	2.73
T_5	K_2O (75%) + Cu (75%) Foliar application	2.52	2.68	2.60
T_6	K_2O (75%) + Cu (100%) Foliar application	2.55	2.70	2.63
T_7	K_2O (75%) + Cu (125%) Foliar application	2.57	2.74	2.66
T_8	K_2O (100%) + Cu (75%) Foliar application	2.60	2.77	2.68
T_9	K_2O (100%) + Cu (100%) Foliar application	2.63	2.80	2.72
T_{10}	K_2O (100%) + Cu (125%) Foliar application	2.67	2.83	2.75
T_{11}	K_2O (125%) + Cu (75%) Foliar application	2.70	2.87	2.78
T_{12}	K_2O (125%) + Cu (100%) Foliar application	2.75	2.90	2.83
T_{13}	K_2O (125%) + Cu (125%) Foliar application	2.80	2.97	2.88
T_{14}	Control + Cu Foliar application	1.57	1.67	1.62
	CD	0.17	0.22	0.16

* RDF = N@187kgha^{-1}, P_2O_5 @62 kgha^{-1}, K_2O@62 kgha^{-1}. N and P doses were same in all the treatments.

Likewise, at harvest maximum leaf area index under the treatment T_{13} (2.47 in 2017, 2.60 in 2018 and 2.53 in the mean data of both the years) than control T_1 with LAI of 0.77 during 2017, 0.90 during 2018 and 0.83 in the mean data of studied years. The fold increase recorded under treatment T_{13}as compared to control T_1 was 3.2 fold in 2017, 2.8 fold in 2018 and 3.0 fold in the mean data. The treatment T_{13} was followed by the treatment T_{12} (2.43 in 2017, 2.51 in 2018 and 2.50 in the mean data) and results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} as a consistent increase in the leaf area index was found (2.40 during 2017, 2.55 during 2018 and 2.48 in the mean data) over the control treatment T_1 which is evident from table 4.9. These results were found to be consistent with research outcomes of Jimenez *et al*. (2011) and Kumar *et al*. (2010). The increased leaf area index mainly at different periods of growth, extend the duration of leaf area by interrupting leaf shedding at maturity, thus leading to increased rate and tuber bulking duration. Potassium application activates metabolism of carbohydrate/protein and thus aid in the carbohydrate translocation from leaves to tubers (Imas and Bansal, 1999).Ferreira *et al.* 2014 observed that use of copper oxychloride as fungicide @ 5.00 g per liter, significantly affected growth of plant during the end of the cycle, ultimately contributing towards increased leaf area and leaf blade dry matter that might have possibly permitted the plants to possess excellent tuber dry matter yield as compared to treatment of copper oxychloride @1.25 and 2.50 g per liter.

Table 4.9 Effect of different treatments on leaf area index at harvest

Treatments*		Leaf area index at harvest		
		I^{st} year (2017-18)	2^{nd} year (2018-19)	Mean
T_1	Control	0.77	0.90	0.83
T_2	100% K_2O (RDF)	2.20	2.43	2.32
T_3	75% K_2O (RDF)	1.93	2.07	2.00
T_4	125% K_2O (RDF)	2.37	2.52	2.44
T_5	K_2O (75%) + Cu (75%) Foliar application	2.00	2.10	2.05
T_6	K_2O (75%) + Cu (100%) Foliar application	2.10	2.15	2.13
T_7	K_2O (75%) + Cu (125%) Foliar application	2.17	2.20	2.18
T_8	K_2O (100%) + Cu (75%) Foliar application	2.23	2.45	2.34
T_9	K_2O (100%) + Cu (100%) Foliar application	2.30	2.48	2.39
T_{10}	K_2O (100%) + Cu (125%) Foliar application	2.33	2.50	2.42
T_{11}	K_2O (125%) + Cu (75%) Foliar application	2.40	2.55	2.48
T_{12}	K_2O (125%) + Cu (100%) Foliar application	2.43	2.57	2.50
T_{13}	K_2O (125%) + Cu (125%) Foliar application	2.47	2.60	2.53
T_{14}	Control + Cu Foliar application	1.00	1.17	1.08
	CD	0.19	0.23	0.15

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

4.1.5 Effect of different treatments on number of haulms

The data presented in table 4.10 depicts the mean number of haulms of potato under different treatments. Application of potassium, copper and their combinations led to non-variable changes on number of haulms plant^{-1}during 1st and 2nd year. In the 1st and 2nd year, the number of haulms plant^{-1} was found to be less than 5 and treatments also had negligible effect this parameter. Singh and Lal (2010) found that stems per plant depend upon variety of things such as variety, seed size and the physiological status that are genetic factors and don't get affected by fertilizer doses.

Table 4.10 Effect of different treatments on number of haulms per plant

Treatments*		No. of haulms per plant		
		Ist year (2017-18)	2nd year (2018-19)	Pooled
T_1	Control	3.50	3.73	3.62
T_2	100% K_2O (RDF)	4.17	4.33	4.25
T_3	75% K_2O (RDF)	4.00	4.10	4.05
T_4	125% K_2O (RDF)	4.33	4.40	4.37
T_5	K_2O (75%) + Cu (75%) Foliar application	4.07	4.15	4.11
T_6	K_2O (75%) + Cu (100%) Foliar application	4.13	4.20	4.17
T_7	K_2O (75%) + Cu (125%) Foliar application	4.18	4.25	4.22
T_8	K_2O (100%) + Cu (75%) Foliar application	4.20	4.30	4.25
T_9	K_2O (100%) + Cu (100%) Foliar application	4.25	4.35	4.30
T_{10}	K_2O (100%) + Cu (125%) Foliar application	4.30	4.40	4.35
T_{11}	K_2O (125%) + Cu (75%) Foliar application	4.33	4.43	4.38
T_{12}	K_2O (125%) + Cu (100%) Foliar application	4.40	4.47	4.43
T_{13}	K_2O (125%) + Cu (125%) Foliar application	4.47	4.60	4.55
T_{14}	Control + Cu Foliar application	3.70	3.90	3.78
	CD	NS	NS	NS

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

4.2. Development studies

The development related traits studied under different treatments such as days to emergence and to maturity of potato have been showed in table 4.11 and 4.12.

4.2.1. Days to emergence:

The findings showed in table no. 4.11 revealed that the application of potassium, copper and their combinations posed non-significant effect on the days to emergence.

Table 4.11 Effect of different treatments on days to emergence of potato

Treatments*		Days to emergence (number)		
		I^{st} year (2017-18)	2^{nd} year (2018-19)	Mean
T_1	Control	15.40	15.00	15.20
T_2	100% K_2O (RDF)	15.20	15.00	15.10
T_3	75% K_2O (RDF)	14.40	14.80	14.60
T_4	125% K_2O (RDF)	15.20	15.00	15.10
T_5	K_2O (75%) + Cu (75%) Foliar application	14.40	14.10	14.25
T_6	K_2O (75%) + Cu (100%) Foliar application	15.20	14.40	14.80
T_7	K_2O (75%) + Cu (125%) Foliar application	14.40	14.43	14.42
T_8	K_2O (100%) + Cu (75%) Foliar application	15.20	14.57	14.88
T_9	K_2O (100%) + Cu (100%) Foliar application	14.40	14.00	14.20
T_{10}	K_2O (100%) + Cu (125%) Foliar application	15.20	14.93	15.07
T_{11}	K_2O (125%) + Cu (75%) Foliar application	14.40	15.00	14.70
T_{12}	K_2O (125%) + Cu (100%) Foliar application	15.20	15.10	15.15
T_{13}	K_2O (125%) + Cu (125%) Foliar application	15.07	14.70	14.88
T_{14}	Control + Cu Foliar application	15.53	15.57	15.55
	CD	NS	NS	NS

* RDF = N@187kgha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

4.2.2 Days to maturity

The data presented in table no. 4.12 revealed that application of potassium, copper and their combinations had non-significant effect on the days to maturity.

Table 4.12 Effect of different treatments on days to maturity of potato

Treatments*		Days to maturity (number)		
		I^{st} year (2017-18)	2^{nd} year (2018-19)	Mean
T_1	Control	78.50	78.73	78.62
T_2	100% K_2O (RDF)	79.17	79.33	79.25
T_3	75% K_2O (RDF)	79.00	79.10	79.05
T_4	125% K_2O (RDF)	79.33	79.40	79.37
T_5	K_2O (75%) + Cu (75%) Foliar application	79.07	79.15	79.11
T_6	K_2O (75%) + Cu (100%) Foliar application	79.13	79.20	79.17

T_7	K_2O (75%) + Cu (125%) Foliar application	79.18	79.25	79.22
T_8	K_2O (100%) + Cu (75%) Foliar application	79.20	79.30	79.25
T_9	K_2O (100%) + Cu (100%) Foliar application	79.25	79.35	79.30
T_{10}	K_2O (100%) + Cu (125%) Foliar application	79.30	79.40	79.35
T_{11}	K_2O (125%) + Cu (75%) Foliar application	79.83	79.93	79.88
T_{12}	K_2O (125%) + Cu (100%) Foliar application	79.90	79.97	79.93
T_{13}	K_2O (125%) + Cu (125%) Foliar application	80.00	80.10	80.05
T_{14}	Control + Cu Foliar application	78.67	78.90	78.78
	CD	NS	NS	NS

* RDF = N@187kgha^{-1}, P_2O_5 @62 kgha^{-1}, K_2O@62 kgha^{-1}. N and P doses were same in all the treatments.

4.3 Yield attributes and yield

4.3.1 Number of plants meter^{-2}

A glance of data shown in table 4.13 revealed that the application of potassium, copper and their combinations posed a non-significant effect on the number of plants per meter square.

Table 4.13 Effect of different treatments on number of plants per square meter of potato

Treatments*		Number of plants per square meter		
		Ist year (2017-18)	2nd year (2018-19)	Mean
T_1	Control	7.94	7.91	7.92
T_2	100% K_2O (RDF)	8.01	7.99	8.00
T_3	75% K_2O (RDF)	7.93	7.98	7.96
T_4	125% K_2O (RDF)	8.00	7.99	8.00
T_5	K_2O (75%) + Cu (75%) Foliar application	7.91	7.92	7.91
T_6	K_2O (75%) + Cu (100%) Foliar application	7.93	7.94	7.94
T_7	K_2O (75%) + Cu (125%) Foliar application	7.91	7.95	7.93
T_8	K_2O (100%) + Cu (75%) Foliar application	7.98	7.96	7.97
T_9	K_2O (100%) + Cu (100%) Foliar application	7.93	7.91	7.92
T_{10}	K_2O (100%) + Cu (125%) Foliar application	7.97	7.99	7.98
T_{11}	K_2O (125%) + Cu (75%) Foliar application	7.99	7.99	7.99
T_{12}	K_2O (125%) + Cu (100%) Foliar application	7.99	8.00	8.00
T_{13}	K_2O (125%) + Cu (125%) Foliar application	7.99	7.97	7.98
T_{14}	Control + Cu Foliar application	7.92	7.90	7.91
	CD	NS	NS	NS

* RDF = N@187kgha^{-1}, P_2O_5 @62 kgha^{-1}, K_2O@62 kgha^{-1}. N and P doses were same in all the treatments.

4.3.2 Average number of tubers per plant

A glance of data given in table 4.14 showed a variable increase in the mean no. of tubers plant^{-1}. The treatment of potassium, copper and its combination recorded the maximum number of tubers under the treatment T_{13} (8.67 in 2017, 9.20 in 2018 and 8.93 in the mean of both the years) over the control treatment T_1 with the number of tubers of 4.87 during 2017, 5.00 during 2018 and 4.93 in the average of both the years. The increase was recorded to be maximum in T_{13} over the control T_1 as1.7 folds in 2017, 1.84 fold in 2018 and 1.8 fold in the mean data. The treatment T_{13} was followed by the treatment T_{12} (8.50 in 2017, 9.00 in 2018 and 8.75 in the mean data) and the results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} (7.90 during 2017, 8.50 during 2018 and 8.20 in the mean data) over the control treatment T_1 which is evident from table 4.14. Similarly, treatment of potassium fertilizer @ 100 kg/ha in potato crop led to rising number of tubers plant^{-1} and also the mean weight of tubers plant^{-1} (Adhikary and Karki 2006). Another study conducted by Jobori and Hadithy (2014) showed that zinc, manganese, iron and copper application increased dry matter percentage and no. of tubers per plant. The observed increase might be due to the paramount function of potassium and copper in photosynthesis that favoured high energy status, ultimately helping the crop for proper nutrients translocation and water absorption by roots, which eventually led to accessibility of more photosynthates to yield higher no. of tubers plant^{-1} (Bergmann, 1992).

Table 4.14 Effect of different treatments on average number of tubers per plant of potato

Treatments*		Average number of tubers per plant		
		Ist year (2017-18)	2nd year (2018-19)	Mean
T_1	Control	4.87	5.00	4.93
T_2	100% K_2O (RDF)	7.50	8.00	7.75
T_3	75% K_2O (RDF)	6.80	7.00	6.90
T_4	125% K_2O (RDF)	7.80	8.20	8.00
T_5	K_2O (75%) + Cu (75%) Foliar application	6.93	7.17	7.05
T_6	K_2O (75%) + Cu (100%) Foliar application	7.00	7.37	7.18
T_7	K_2O (75%) + Cu (125%) Foliar application	7.37	7.47	7.42
T_8	K_2O (100%) + Cu (75%) Foliar application	7.57	8.03	7.80
T_9	K_2O (100%) + Cu (100%) Foliar application	7.67	8.13	7.90
T_{10}	K_2O (100%) + Cu (125%) Foliar application	7.80	8.30	8.05
T_{11}	K_2O (125%) + Cu (75%) Foliar application	7.90	8.50	8.20
T_{12}	K_2O (125%) + Cu (100%) Foliar application	8.50	9.00	8.75
T_{13}	K_2O (125%) + Cu (125%) Foliar application	8.67	9.20	8.93
T_{14}	Control + Cu Foliar application	5.33	5.50	5.42
	CD	0.60	0.89	0.53

* RDF = N@187kgha^{-1}, P_2O_5 @62 kgha^{-1}, K_2O@62 kgha^{-1}. N and P doses were same in all the treatments.

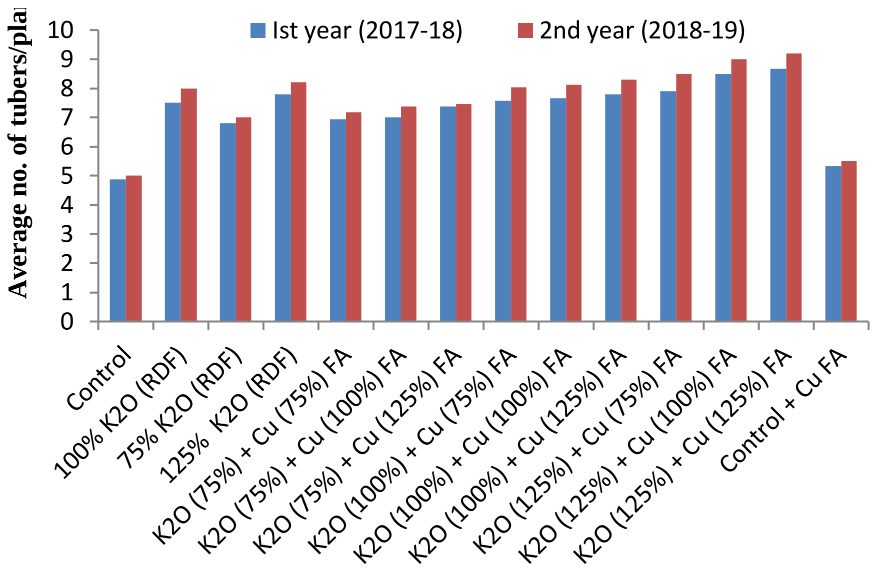

Fig 4.1.Effect of different treatments on average number of tubers per plant of potato

4.3.3 Average weight of tuber

The data shown in table 4.15 indicated a differential variation in the average weight of tubers with various treatments. The application of potassium, copper and its combination recorded the maximum average tuber weight under the treatment T_{13} (47g in 2017, 48.67g in 2018 and 47.83g in the mean of both the years) over the control treatment T_1 with the average tuber weight of 29g during 2017, 30.67g during 2018 and 29.83g in the mean data of both the years. The increase was recorded to be maximum in T_{13} over the control $T_{1,}$ reported as 1.62 fold in 2017, 1.58 fold in 2018 and 1.6 fold in the mean data. The treatment T_{13} was followed by the treatment T_{12} (46 g in 2017, 46.33g in 2018 and 46.72g in the mean) and results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} as significant increase in the tuber weight was recorded (45.5g during 2017, 46.33g during 2018 and 45.62g in the average) over the control treatment T_1 which is evident from table 4.15.

The findings of present study were at par with observations of Chopra *et al.* (2006) where potassium application led to maximum tuber weight along with highest number of tubers. In another study conducted by Musawy and Amiry (2017), it was found that copper application increased average tuber weight. The observed increase in yield attributes could be due to treatment of potassium and copper that enhanced photosynthesis, phloem loading and its translocation, contributing towards the synthesis of large molecular weight substances in storage organs, thus contributing to the rapid bulking of the tubers (Singh, 1999).

Table 4.15 Effect of different treatments on average weight of tuber of potato

Treatments*		Average weight of tuber (g)		
		Ist year (2017-18)	2nd year (2018-19)	Mean
T_1	Control	29.00	30.67	29.83
T_2	100% K_2O (RDF)	41.00	42.13	41.57
T_3	75% K_2O (RDF)	37.00	38.00	37.50
T_4	125% K_2O (RDF)	44.17	45.10	44.63
T_5	K_2O (75%) + Cu (75%) Foliar application	37.33	38.67	38.00
T_6	K_2O (75%) + Cu (100%) Foliar application	39.20	39.90	39.55
T_7	K_2O (75%) + Cu (125%) Foliar application	39.67	40.33	40.00
T_8	K_2O (100%) + Cu (75%) Foliar application	42.00	43.00	42.50
T_9	K_2O (100%) + Cu (100%) Foliar application	43.50	44.00	43.75
T_{10}	K_2O (100%) + Cu (125%) Foliar application	44.00	44.83	44.42
T_{11}	K_2O (125%) + Cu (75%) Foliar application	45.50	46.33	45.92
T_{12}	K_2O (125%) + Cu (100%) Foliar application	46.00	47.43	46.72
T_{13}	K_2O (125%) + Cu (125%) Foliar application	47.00	48.67	47.83
T_{14}	Control + Cu Foliar application	30.33	31.33	30.83
	CD	2.39	3.60	2.47

* RDF = N@187kgha^{-1}, P_2O_5 @62 kgha^{-1}, K_2O@62 kgha^{-1}. N and P doses were same in all the treatments.

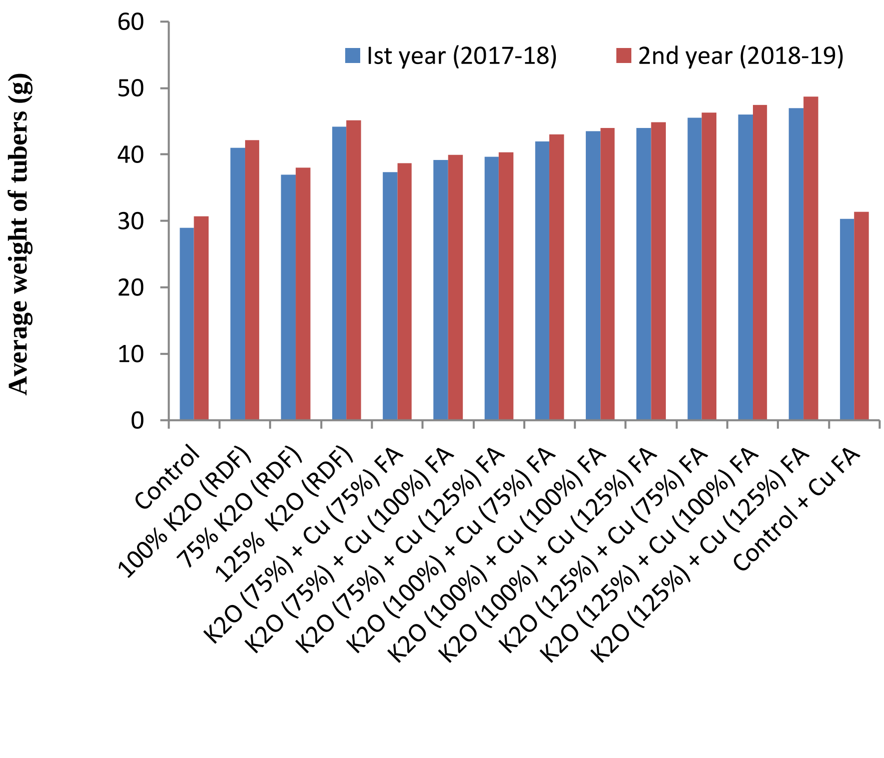

Fig.4.2 Effect of different treatments on average weight of tuber of potato

4.3.4 Average weight of tubers per plant

The data in table 4.16 showed a differential response in the average weight of tubers per plant. Among different treatments of potassium, copper and its combination, the maximum average tuber weight per plant was observed under treatment T_{13} (415.49 g in 2017, 455.73 g in 2018 and 432.78 g in the mean of both the years) over the control treatment T_1 with the average tuber weight per plant of 149.23 g during 2017, 161.33 g during 2018 and 152.45 g in the mean of both studied years. The rise recorded in T_{13}in contrast to control T_1 was 2.7 fold in 2017, 2.8 fold in 2018 and 2.8 fold in the mean data. The treatment T_{13} was followed by the treatment T_{12} (399 g in 2017, 434.90 g in 2018 and 414.12 g in the mean) and results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} as significant increase in the average tuber weight per plant was recorded (367.45 g during 2017, 401.83 g during 2018 and 381.81 g in the mean data) over the control treatment T_1 which is evident from table 4.16. Likewise, earlier reports depicted that potassium application led to increased average weight of tubers (Panique *et al.*1997). Also, a study revealed that application of potassium fertilizer in potato @ 100 kg/ha led to a gradual increase in the mean weight of tubers per plant (Adhikary and Karki 2006). Musawy and Amiry (2017) reported that copper foliar application increased average weight of tubers per plant. The increase was attributed due to the stimulatory effects of potassium and copper on photosynthesis, phloem loading and translocation and synthesis of large molecular weight substances with in storage organs that contributes to the rapid bulking of the tubers.

Table 4.16 Effect of different treatments on average weight of tubers per plant of potato

Treatments*		Average weight of tubers per plant (g)		
		Ist year (2017-18)	2nd year (2018-19)	Mean
T_1	Control	149.23	161.33	152.45
T_2	100% K_2O (RDF)	315.50	345.07	327.45
T_3	75% K_2O (RDF)	259.60	274.00	263.97
T_4	125% K_2O (RDF)	352.50	377.82	362.33
T_5	K_2O (75%) + Cu (75%) Foliar application	266.72	285.24	273.15
T_6	K_2O (75%) + Cu (100%) Foliar application	282.40	302.06	289.40
T_7	K_2O (75%) + Cu (125%) Foliar application	300.34	309.29	301.98
T_8	K_2O (100%) + Cu (75%) Foliar application	325.94	353.29	336.78
T_9	K_2O (100%) + Cu (100%) Foliar application	341.65	365.72	350.85
T_{10}	K_2O (100%) + Cu (125%) Foliar application	351.20	380.12	362.83
T_{11}	K_2O (125%) + Cu (75%) Foliar application	367.45	401.83	381.81
T_{12}	K_2O (125%) + Cu (100%) Foliar application	399.00	434.90	414.12
T_{13}	K_2O (125%) + Cu (125%) Foliar application	415.49	455.73	432.78
T_{14}	Control + Cu Foliar application	169.68	180.33	172.17
	CD	18.26	29.70	19.69

* RDF = N@187kgha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

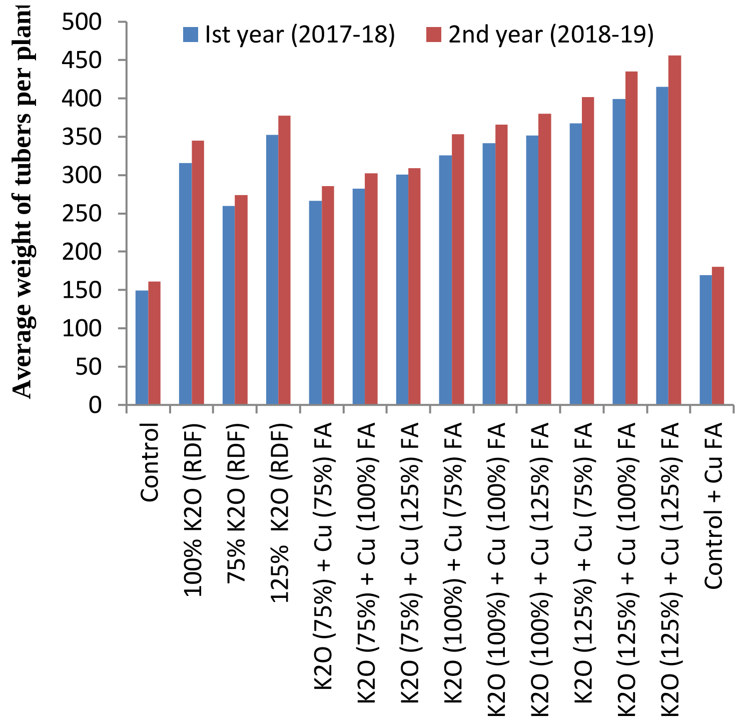

Fig. 4.3 Effect of different treatments on average weight of tubers per plant of potato

4.3.5 Tuber yield

The data in table 4.17 depicted a significant increase in the tuber yield. The application of potassium, copper and its combination recorded the maximum tuber yield under the treatment T_{13} (331.98 q ha^{-1} in 2017, 363.22q ha^{-1}in 2018 and 347.50q ha^{-1}in the mean of both the years) over the control treatment T_1 with the tuber yield of 118.49q ha^{-1}during 2017, 127.61q ha^{-1} during 2018 and 123.08 q ha^{-1} in the mean data of both the years. The percent increase recorded in T_{13} over the control T_1 was 64% in 2017, 64% in 2018 and 64% in the mean data. The treatment T_{13} was followed by the treatment T_{12} (318.90q ha^{-1} in 2017, 347.92q ha^{-1} in 2018 and 332.83q ha^{-1} in the mean data) and results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} as significant increase in the average tuber weight per plant was recorded (293.59q ha^{-1}during 2017, 321.06q ha^{-1} during 2018 and 307.67q ha^{-1} in the mean data) over the control treatment T_1 which is evident from table 4.17. In harmony with this study, Adhikari and Sharma (2004), Eremeev *et al.* (2009) and Eleiwa *et al.* (2012) reported that increasing NPK doses significantly enhanced the tuber yield and the yield related parameters of potato at harvest. In another study conducted by Hashemy *et al.* (1998), it was observed that micronutrient (Zn, Mn, Fe and Cu) application led to increased no. of tuber plant^{-1}, tuber yield and dry matter percentage under full concentration of micronutrient. This increase was as a result of pivotal effect of micronutrients on photosynthesis that favoured high energy status and eventually aided timely translocation of nutrients in crop plants, leading to availability of more photosynthates for production of more tubers per plant (Bergmann, 1992).

Table 4.17 Effect of different treatments on tuber yield (q ha^{-1}) of potato

Treatments*		Tuber yield		
		Ist year (2017-18)	2nd year (2018-19)	Mean
T_1	Control	118.49	127.61	123.08
T_2	100% K_2O (RDF)	252.72	275.71	263.83
T_3	75% K_2O (RDF)	205.86	218.65	211.83
T_4	125% K_2O (RDF)	282.00	301.88	292.17
T_5	K_2O (75%) + Cu (75%) Foliar application	210.98	225.91	218.00
T_6	K_2O (75%) + Cu (100%) Foliar application	223.94	239.84	231.50
T_7	K_2O (75%) + Cu (125%) Foliar application	237.57	245.89	241.50
T_8	K_2O (100%) + Cu (75%) Foliar application	260.10	281.22	270.83
T_9	K_2O (100%) + Cu (100%) Foliar application	270.93	289.28	279.67
T_{10}	K_2O (100%) + Cu (125%) Foliar application	279.91	303.72	291.50
T_{11}	K_2O (125%) + Cu (75%) Foliar application	293.59	321.06	307.67
T_{12}	K_2O (125%) + Cu (100%) Foliar application	318.80	347.92	332.83
T_{13}	K_2O (125%) + Cu (125%) Foliar application	331.98	363.22	347.50
T_{14}	Control + Cu Foliar application	134.39	142.46	138.33
	CD	14.41	20.24	13.73

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

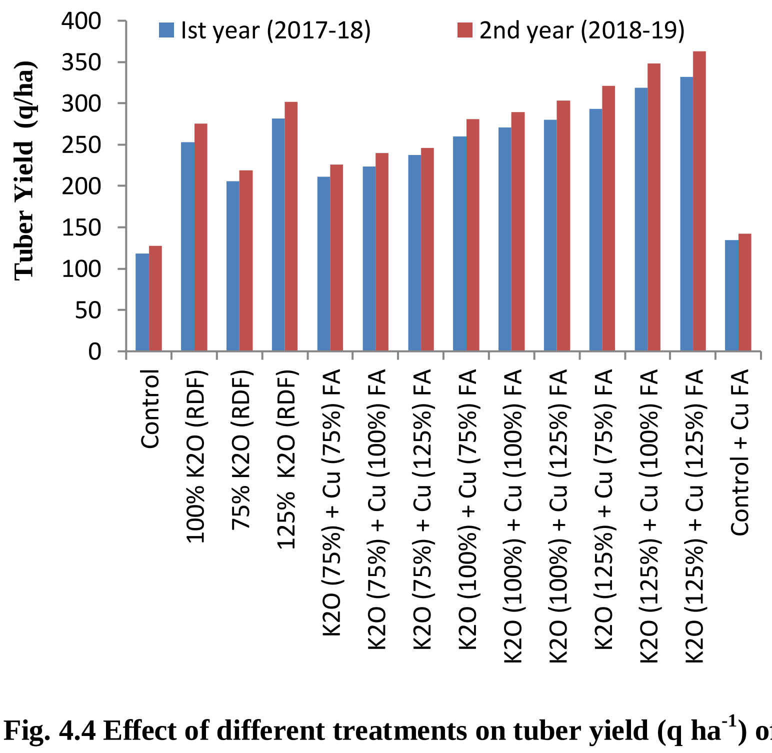

Fig. 4.4 Effect of different treatments on tuber yield (q ha^{-1}) of potato

4.3.6 Haulm Yield

The data in table 4.18 depicted a considerable increase in the haulm yield of potato. The treatments including potassium, copper and its combination recorded the maximum haulm yield under the treatment T_{13} (27.83 q/ha in 2017, 28.43 q/ha in 2018 and 28.13 q/ha in the mean of both the years) over the control treatment T_1 with the haulm yield of 18.60 q/ha during 2017, 18.97 q/ha during 2018 and 18.78 q/ha in the average of both the years. The percent increase was recorded to be 33 % in T_{13} over the control T_1. The treatment T_{13} was followed by the treatment T_{12} (27.17 q/ha in 2017, 27.83 q/ha in 2018 and 27.50 q/ha in the mean data) and the results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} (26.37 q/ha during 2017, 27.17 q/ha during 2018 and 26.77 q/ha in the mean data) over the control treatment T_1 which is evident from table 4.18. The results obtained in haulm yield were in consistent with tuber yield. Similar observations have been reported in investigation carried by Pawar *et al.* (2002).

Table 4.18 Effect of different treatments on haulm yield (q ha^{-1}) of potato

Treatments*		Haulm yield (q/ha)		
		I^{st} year (2017-18)	2^{nd} year (2018-19)	Mean
T_1	Control	18.60	18.97	18.78
T_2	100% K_2O (RDF)	24.67	25.17	24.92
T_3	75% K_2O (RDF)	22.20	23.13	22.67
T_4	125% K_2O (RDF)	26.27	26.77	26.52
T_5	K_2O (75%) + Cu (75%) Foliar application	22.67	23.37	23.02
T_6	K_2O (75%) + Cu (100%) Foliar application	23.37	24.30	23.83
T_7	K_2O (75%) + Cu (125%) Foliar application	24.13	25.03	24.58
T_8	K_2O (100%) + Cu (75%) Foliar application	25.07	25.47	25.27
T_9	K_2O (100%) + Cu (100%) Foliar application	25.37	26.10	25.73
T_{10}	K_2O (100%) + Cu (125%) Foliar application	26.13	26.73	26.43
T_{11}	K_2O (125%) + Cu (75%) Foliar application	26.37	27.17	26.77
T_{12}	K_2O (125%) + Cu (100%) Foliar application	27.17	27.83	27.50
T_{13}	K_2O (125%) + Cu (125%) Foliar application	27.83	28.43	28.13
T_{14}	Control + Cu Foliar application	19.54	20.54	20.04
	CD	3.29	4.01	1.69

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

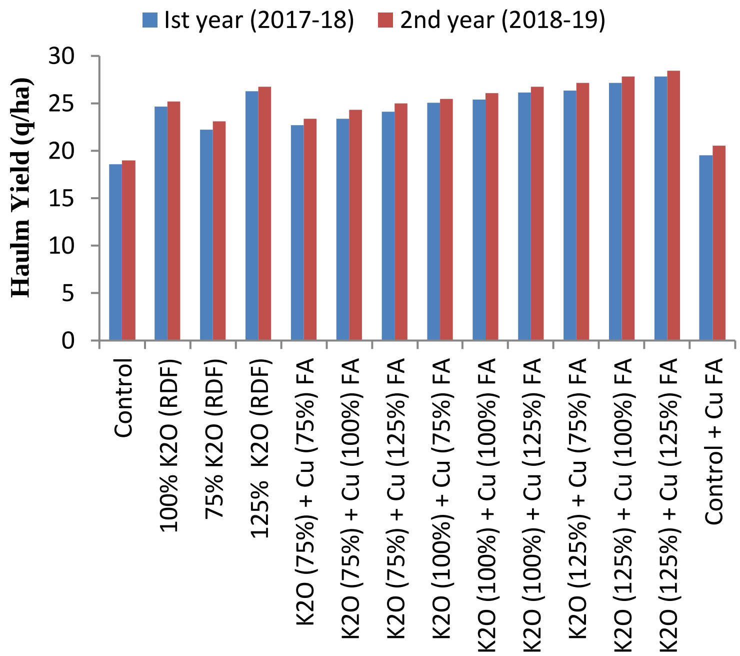

Fig.4.5 Effect of different treatments on haulm yield (q ha^{-1}) of potato

4.4 Quality Parameters

4.4.1 Starch content

The data presented in the table 4.19 showed a differential increase in the starch content of potato tubers. The treatments of potassium, copper and its combination recorded the maximum starch content under the treatment T_{13} (14.67% in 2017, 14.83% in 2018 and 14.75%in the mean of both the years) over the control treatment T_1 with the specific gravity of 11% during 2017, 11.30% during 2018 and 11.15% in the average of both the years. The percent increase was recorded to be 25 % in 2017, 23% in 2018 and 24% in the mean of both the years under treatment T_{13} over the control T_1. The treatment T_{13} was followed by the treatment T_{12} (14.33% in 2017, 14.57% in 2018 and 14.45% in the mean data) and the results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} (14% during 2017, 14.37% during 2018 and 14.18% in the mean data) over the control treatment T_1 which is evident from table 4.19. Similarly, starch content was found to increase under potassium treatment @249kg/hectare (Mello *et al.* 2018). An earlier study conducted by Romemheld and El-Fouly (1999) showed that copper spray was the efficient medium to enhance quality and yield of potato crop as depicted by increased vitamin C, starch and sugar contents.

Table 4.19 Effect of different treatments on starch content in potato tubers

Treatments*		Starch content (%)		
		I[st] year (2017-18)	2[nd] year (2018-19)	Mean
T_1	Control	11.00	11.30	11.15
T_2	100% K_2O (RDF)	13.10	13.40	13.25
T_3	75% K_2O (RDF)	12.00	12.50	12.25
T_4	125% K_2O (RDF)	13.70	13.83	13.77
T_5	K_2O (75%) + Cu (75%) Foliar application	12.30	12.53	12.42
T_6	K_2O (75%) + Cu (100%) Foliar application	12.50	13.00	12.75
T_7	K_2O (75%) + Cu (125%) Foliar application	12.90	13.23	13.07
T_8	K_2O (100%) + Cu (75%) Foliar application	13.30	13.67	13.48
T_9	K_2O (100%) + Cu (100%) Foliar application	13.50	13.90	13.70
T_{10}	K_2O (100%) + Cu (125%) Foliar application	13.77	13.93	13.85
T_{11}	K_2O (125%) + Cu (75%) Foliar application	14.00	14.37	14.18
T_{12}	K_2O (125%) + Cu (100%) Foliar application	14.33	14.57	14.45
T_{13}	K_2O (125%) + Cu (125%) Foliar application	14.67	14.83	14.75
T_{14}	Control + Cu Foliar application	11.50	11.73	11.62
	CD	1.12	1.24	1.15

* RDF = N@187kgha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

4.4.2 Vitamin C

The data presented in the table 4.20 depicted a magnificent rise in vitamin C content. Treatment of potassium, copper and its combination recorded the highest content of vitamin C under the treatment T_{13} (19.83 mg/100g in 2017, 20.00 mg/100g in 2018 and 19.92 mg/100g in the mean of both the years) over the control treatment T_1 with the vitamin C content of 16.83 mg/100g during 2017, 17.00 mg/100g during 2018 and 16.92 mg/100g in the average of both the years. The percent increase was recorded to be 15% in T_{13} over the control T_1. The treatment T_{13} was followed by the treatment T_{12} (19.67 mg/100g in 2017, 19.83 mg/100g in 2018 and 19.75 mg/100g in the mean data) and the results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} (19.50 mg/100g during 2017, 19.67 mg/100g during 2018 and 19.58 mg/100g in the mean data) over the control treatment T_1 which is evident from table 4.20. The results were found in accordance with Smith and Smith (1977), who elucidated that contents of vitamin C increased by 10.8% and 14.7% upon application of potassium as sulphate of potash and muriate of potash @ 150 kg K/ha. A previous study of Grewal and Trehan (1979) found that micronutrients such as zinc, manganese, copper, molybdenum and boron increased the contents of ascorbic acid in tubers.

Table 4.20 Effect of different treatments on vitamin C content of tubers

Treatments*		Vitamin C content of tubers (mg/100g)		
		Ist year (2017-18)	2^{nd} year (2018-19)	Mean
T_1	Control	16.83	17.00	16.92
T_2	100% K_2O (RDF)	18.00	18.17	18.08
T_3	75% K_2O (RDF)	17.83	18.00	17.92
T_4	125% K_2O (RDF)	19.33	19.50	19.42
T_5	K_2O (75%) + Cu (75%) Foliar application	17.90	18.07	17.98
T_6	K_2O (75%) + Cu (100%) Foliar application	18.00	18.17	18.08
T_7	K_2O (75%) + Cu (125%) Foliar application	18.17	18.33	18.25
T_8	K_2O (100%) + Cu (75%) Foliar application	18.33	18.50	18.42
T_9	K_2O (100%) + Cu (100%) Foliar application	18.70	18.87	18.78
T_{10}	K_2O (100%) + Cu (125%) Foliar application	18.80	18.97	18.88
T_{11}	K_2O (125%) + Cu (75%) Foliar application	19.50	19.67	19.58
T_{12}	K_2O (125%) + Cu (100%) Foliar application	19.67	19.83	19.75
T_{13}	K_2O (125%) + Cu (125%) Foliar application	19.83	20.00	19.92
T_{14}	Control + Cu Foliar application	17.00	17.17	17.08
	CD	1.09	0.95	1.01

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

4.4.3 Specific gravity

The data presented in the table 4.21 reflected gradually high specific gravity in potato tubers. The application of potassium, copper and its combination recorded the maximum specific gravity under the treatment T_{13} (1.089 in 2017, 1.090 in 2018 and 1.080 in the mean of both the years) over the control treatment T_1 with the specific gravity of 1.050 during 2017, 1.053 during 2018 and 1.051 in the average of both the years. The percent increase was recorded to be 3 % in T_{13} over the control T_1. The treatment T_{13} was followed by the treatment T_{12} (1.088 in 2017, 1.089 in 2018 and 1.088 in the mean data) and the results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} (1.087 during 2017, 1.088 during 2018 and 1.088 in the mean data) over the control treatment T_1 which is evident from table 4.21. The results were found to be in accordance with the findings of Khan *et al*. (2010) where gradual increase in specific gravity of potato tubers was observed with potassium treatment @ 150 kg/ha in contrast to potassium treatment @ 225 kg/ha (Khan *et al.* 2010). Another study by Sammy *et al.*(2015) found that foliar spray of copper was an effective method for increasing the quality of potato crop.

Table 4.21 Effect of different treatments on specific gravity of potato

Treatments*		Specific gravity		
		I^{st} year (2017-18)	2^{nd} year (2018-19)	Mean
T_1	Control	1.050	1.053	1.051
T_2	100% K_2O (RDF)	1.083	1.084	1.087
T_3	75% K_2O (RDF)	1.080	1.081	1.081
T_4	125% K_2O (RDF)	1.087	1.088	1.081
T_5	K_2O (75%) + Cu (75%) Foliar application	1.080	1.081	1.082
T_6	K_2O (75%) + Cu (100%) Foliar application	1.081	1.081	1.084
T_7	K_2O (75%) + Cu (125%) Foliar application	1.082	1.083	1.084
T_8	K_2O (100%) + Cu (75%) Foliar application	1.083	1.084	1.086
T_9	K_2O (100%) + Cu (100%) Foliar application	1.084	1.085	1.087
T_{10}	K_2O (100%) + Cu (125%) Foliar application	1.085	1.086	1.088
T_{11}	K_2O (125%) + Cu (75%) Foliar application	1.087	1.088	1.090
T_{12}	K_2O (125%) + Cu (100%) Foliar application	1.088	1.089	1.088
T_{13}	K_2O (125%) + Cu (125%) Foliar application	1.089	1.090	1.080
T_{14}	Control + Cu Foliar application	1.056	1.060	1.087
	CD	0.02	0.02	0.01

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

4.4.4 Grading of Potato tubers

The response of various treatments on grading of potato tubers in the year 2017-18, 2018-19 and the mean data for both years was found to be significant and has been presented in table 4.22, 4.23 and 4.24.

Among different treatments in the year 2017-18, 2018-19 and in the mean data, the treatment T_{13} led to highest production of grade A tubers followed by grade B tubers. However, highest tuber yield of 'C' grade tubers was observed under treatment combination K_2O (75%) and Cu (125%).The results were found in accordance with Moinuddin *et al.* (2004, 2005) where high potassium application (from 0 to 225 kg K_2O per hectare) led to increased the tuber yield, yield of large and medium grade tubers.

i. **A grade tuber:**

The data revealed that the studied combinations of treatments resulted inconsiderable effect on A grade tubers. The yield of A grade tubers was recorded to be highest under treatment T_{13} in contrast to control. Furthermore, it was followed by T_{12} and T_{11}, respectively.

ii. **B grade tuber:**

Different treatment combinations showed a significant effect on B grade tubers. The yield of B grade tubers was reported to be highest in treatment T_{13} in contrast to control. Furthermore, it was found that the treatment T_{13} followed T_{12} and T_{11}.

iii. **C grade tuber:**

Various combinations of studied treatments showed significant effect on C grade tubers. Yield of C grade tubers was significantly highest in treatment T_7 as compared to control. Furthermore, it was followed by T_6 respectively.

Higher yield of large sized tubers is due to improved nutrition of the crop as sufficient supply of micronutrients was supplied in the form of potassium and copper under treatment T_{13} which might have resulted into more tuber bulking as compared to other treatments.

Table 4.22 Effect of different treatments on graded yield (qha^{-1}) of potato tubers (2017-18)

Treatments*		Ist year (2017-18)		
		Grade A (>75 g)	Grade B (50-75 g)	Grade C (<50 g)
T_1	Control	35.90	43.88	38.72
T_2	100% K_2O (RDF)	104.84	94.75	53.08
T_3	75% K_2O (RDF)	63.67	76.71	65.29
T_4	125% K_2O (RDF)	119.27	112.17	51.23
T_5	K_2O (75%) + Cu (75%) Foliar application	65.22	78.60	66.85
T_6	K_2O (75%) + Cu (100%) Foliar application	69.24	83.43	71.00
T_7	K_2O (75%) + Cu (125%) Foliar application	73.47	88.52	75.34
T_8	K_2O (100%) + Cu (75%) Foliar application	108.00	97.64	54.69
T_9	K_2O (100%) + Cu (100%) Foliar application	112.00	101.50	56.50
T_{10}	K_2O (100%) + Cu (125%) Foliar application	116.04	104.88	58.75
T_{11}	K_2O (125%) + Cu (75%) Foliar application	123.90	116.28	53.49
T_{12}	K_2O (125%) + Cu (100%) Foliar application	134.31	126.32	57.70
T_{13}	K_2O (125%) + Cu (125%) Foliar application	139.94	131.61	60.12
T_{14}	Control + Cu Foliar application	40.70	49.75	43.85
	CD	5.43	5.59	3.25

*RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

Table 4.23 Effect of different treatments on graded yield (qha^{-1}) of potato tubers (2018-19)

Treatments*		IInd year (2018-19)		
		Grade A (>75 g)	Grade B (50-75 g)	Grade C (<50 g)
T_1	Control	38.68	47.28	41.71
T_2	100% K_2O (RDF)	114	103.3	57.70
T_3	75% K_2O (RDF)	67.49	81.34	69.17
T_4	125% K_2O (RDF)	127.28	119.45	54.94
T_5	K_2O (75%) + Cu (75%) Foliar application	69.76	84.07	71.50
T_6	K_2O (75%) + Cu (100%) Foliar application	74.13	89.30	75.90
T_7	K_2O (75%) + Cu (125%) Foliar application	76.05	91.72	77.90
T_8	K_2O (100%) + Cu (75%) Foliar application	116.47	105.76	59.10
T_9	K_2O (100%) + Cu (100%) Foliar application	120.05	108.50	60.78
T_{10}	K_2O (100%) + Cu (125%) Foliar application	125.86	114.00	63.50
T_{11}	K_2O (125%) + Cu (75%) Foliar application	135.72	127.64	58.31
T_{12}	K_2O (125%) + Cu (100%) Foliar application	146.50	137.80	63.00
T_{13}	K_2O (125%) + Cu (125%) Foliar application	153.00	144.17	66.18
T_{14}	Control + Cu Foliar application	43.10	52.71	46.52
	CD	6.25	5.05	2.81

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

Table 4.24 Effect of different treatments on graded yield (qha^{-1}) of potato tubers (mean data)

Treatments*		Mean Data		
		Grade A (>75 g)	Grade B (50-75 g)	Grade C (<50 g)
T_1	Control	37.28	45.60	40.22
T_2	100% K_2O (RDF)	109.54	99.05	55.37
T_3	75% K_2O (RDF)	65.55	79.03	67.22
T_4	125% K_2O (RDF)	123.38	115.82	53.13
T_5	K_2O (75%) + Cu (75%) Foliar application	67.32	81.37	69.17
T_6	K_2O (75%) + Cu (100%) Foliar application	71.77	86.38	73.48
T_7	K_2O (75%) + Cu (125%) Foliar application	74.99	90.15	76.63
T_8	K_2O (100%) + Cu (75%) Foliar application	112.33	101.70	56.90
T_9	K_2O (100%) + Cu (100%) Foliar application	116.17	104.98	58.63
T_{10}	K_2O (100%) + Cu (125%) Foliar application	120.51	109.42	61.13
T_{11}	K_2O (125%) + Cu (75%) Foliar application	129.82	121.97	55.90
T_{12}	K_2O (125%) + Cu (100%) Foliar application	140.49	132.07	60.33
T_{13}	K_2O (125%) + Cu (125%) Foliar application	146.66	137.92	63.13
T_{14}	Control + Cu Foliar application	42.05	51.27	45.20
	CD	3.65	4.34	2.15

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

4.5 Soil Studies

4.5.1 Available potassium content of the soil at harvest

A glance of data shown in the table 4.25 revealed a considerable increase in the available potassium of soil with various treatments. The highest value was recorded under treatment T_{13} (226.20 kg ha^{-1} in 2017, 226.40 kg ha^{-1} in 2018 and 226.30 kg ha^{-1} in the mean of both the years)over the control treatment T_1 (221.83 kg ha^{-1} during 2017, 222.03 kg ha^{-1} during 2018 and 221.93 kg ha^{-1} in the average of both the years. The percent increase was recorded to be 2% in T_{13} over the control T_1. The treatment T_{13} was followed by the treatment T_{12} (226.17 kg per hectare in 2017, 226.37 kg per hectare in 2018 and 226.27 kg ha^{-1} in the mean data) and the results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} (226.13 kg ha^{-1} during 2017, 226.33 kg ha^{-1} during 2018 and 226.23 kg ha^{-1} in the mean data) over the control treatment T_1 which is evident from table 4.25. The recorded enhancement may be due to the progressively increasing utility of nutrients.

Table 4.25 Effect of different treatments on available K_2O status of soil (kg ha^{-1}) after harvest

Treatments*		Available K_2O (kg ha^{-1})		
		Ist year (2017-18)	2^{nd} year (2018-19)	Mean
T_1	Control	221.83	222.03	221.93
T_2	100% K_2O (RDF)	224.73	224.93	224.83
T_3	75% K_2O (RDF)	223.00	223.20	223.10
T_4	125% K_2O (RDF)	226.00	226.20	226.10
T_5	K_2O (75%) + Cu (75%) Foliar application	223.43	223.63	223.53
T_6	K_2O (75%) + Cu (100%) Foliar application	223.50	223.70	223.60
T_7	K_2O (75%) + Cu (125%) Foliar application	223.53	223.73	223.63
T_8	K_2O (100%) + Cu (75%) Foliar application	224.83	225.03	224.93
T_9	K_2O (100%) + Cu (100%) Foliar application	224.87	225.07	224.97
T_{10}	K_2O (100%) + Cu (125%) Foliar application	224.90	225.10	225.00
T_{11}	K_2O (125%) + Cu (75%) Foliar application	226.13	226.33	226.23
T_{12}	K_2O (125%) + Cu (100%) Foliar application	226.17	226.37	226.27
T_{13}	K_2O (125%) + Cu (125%) Foliar application	226.20	226.40	226.30
T_{14}	Control + Cu Foliar application	221.93	222.13	222.03
	CD	1.26	1.22	1.24

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

4.5.2 Potassium content in tuber and haulm

The figures in table 4.26 and 4.27 depicted a differential variation in the contents of potassium in tubers and haulms under various treatments. The highest contents were recorded under treatment T_{13}over the control treatment T_1. The percent increase in potassium content was recorded to be 66% in tubers and 32% in haulm under T_{13} over the control T_1. The treatment T_{13} was followed by the treatment T_{12} and subsequently by T_{11}, as evident from table 4.26 and 4.27. These results were according to observations of Gayathri *et al.* (2008). The higher potassium content observed in potato tubers and haulm could be due to the improved growth and development of crop plants under different treatments which might have increased the accessibility of minerals in soil solution and facilitated the plant roots to absorb higher nutrients from the soil.

Table 4.26 Effect of different treatments on K content in tuber

Treatments*		K content in tuber (%)		
		Ist year (2017-18)	2nd year (2018-19)	Mean
T_1	Control	0.593	0.600	0.597
T_2	100% K_2O (RDF)	1.077	1.083	1.080
T_3	75% K_2O (RDF)	1.037	1.043	1.040
T_4	125% K_2O (RDF)	1.103	1.110	1.107
T_5	K_2O (75%) + Cu (75%) Foliar application	1.037	1.043	1.040
T_6	K_2O (75%) + Cu (100%) Foliar application	1.050	1.057	1.053
T_7	K_2O (75%) + Cu (125%) Foliar application	1.057	1.063	1.060
T_8	K_2O (100%) + Cu (75%) Foliar application	1.077	1.083	1.080
T_9	K_2O (100%) + Cu (100%) Foliar application	1.078	1.085	1.082
T_{10}	K_2O (100%) + Cu (125%) Foliar application	1.079	1.085	1.082
T_{11}	K_2O (125%) + Cu (75%) Foliar application	1.103	1.110	1.107
T_{12}	K_2O (125%) + Cu (100%) Foliar application	1.107	1.113	1.110
T_{13}	K_2O (125%) + Cu (125%) Foliar application	1.108	1.114	1.111
T_{14}	Control + Cu Foliar application	0.643	0.650	0.647
	CD	0.145	0.141	0.143

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

Table 4.27 Effect of different treatments on K content in haulm

Treatments*		K content in haulm (%)		
		Ist year (2017-18)	2nd year (2018-19)	Mean
T_1	Control	0.893	0.900	0.897
T_2	100% K_2O (RDF)	1.297	1.303	1.300
T_3	75% K_2O (RDF)	1.267	1.273	1.270
T_4	125% K_2O (RDF)	1.313	1.320	1.317
T_5	K_2O (75%) + Cu (75%) Foliar application	1.267	1.273	1.270
T_6	K_2O (75%) + Cu (100%) Foliar application	1.280	1.287	1.283
T_7	K_2O (75%) + Cu (125%) Foliar application	1.287	1.293	1.290
T_8	K_2O (100%) + Cu (75%) Foliar application	1.297	1.303	1.300
T_9	K_2O (100%) + Cu (100%) Foliar application	1.298	1.305	1.302
T_{10}	K_2O (100%) + Cu (125%) Foliar application	1.299	1.305	1.302
T_{11}	K_2O (125%) + Cu (75%) Foliar application	1.313	1.320	1.317
T_{12}	K_2O (125%) + Cu (100%) Foliar application	1.317	1.323	1.320
T_{13}	K_2O (125%) + Cu (125%) Foliar application	1.318	1.324	1.321
T_{14}	Control + Cu Foliar application	0.943	0.950	0.947
	CD	0.194	0.181	0.188

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

4.5.3 Copper content in tuber

The statistics shown in the table 4.28 indicated a significant increase in the contents of copper in tubers under different treatment combinations. The highest contents were recorded under treatment T_{13}over the control treatment T_1. The percent increase in copper content was recorded to be 5% in tubers under T_{13} over the control T_1. The treatment T_{13} was followed by the treatment T_{12} and subsequently by T_{11}, as evident from table 4.28. Gaj *et al.* (2020) observed that foliar spray of and micronutrients resulted in increased accumulation of zinc, copper and manganese in tubers of the Hermes variety.

Table 4.28 Effect of different treatments on copper content (mg/kg) in tuber

Treatments*		Copper content (mg/kg) in tuber		
		Ist year (2017-18)	2^{nd} year (2018-19)	Mean
T_1	Control	8.50	8.53	8.52
T_2	100% K_2O (RDF)	8.57	8.60	8.58
T_3	75% K_2O (RDF)	8.55	8.58	8.57
T_4	125% K_2O (RDF)	8.59	8.62	8.61
T_5	K_2O (75%) + Cu (75%) Foliar application	8.79	8.82	8.81
T_6	K_2O (75%) + Cu (100%) Foliar application	8.87	8.90	8.88
T_7	K_2O (75%) + Cu (125%) Foliar application	8.95	8.98	8.97
T_8	K_2O (100%) + Cu (75%) Foliar application	8.81	8.84	8.82
T_9	K_2O (100%) + Cu (100%) Foliar application	8.89	8.92	8.91
T_{10}	K_2O (100%) + Cu (125%) Foliar application	8.97	9.00	8.98
T_{11}	K_2O (125%) + Cu (75%) Foliar application	8.83	8.87	8.85
T_{12}	K_2O (125%) + Cu (100%) Foliar application	8.91	8.95	8.93
T_{13}	K_2O (125%) + Cu (125%) Foliar application	8.99	9.02	9.01
T_{14}	Control + Cu Foliar application	8.67	8.70	8.68
	CD	0.20	0.17	0.18

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

5.1 Harvest index

The data presented in the table 4.29 reflected a gradual rise in the harvest index of potato. The treatments of potassium, copper and its combination recorded the maximum harvest index under the treatment T_{13} (92.30% in 2017, 92.74 % in 2018, 92.52% in the mean of both the years) over the control treatment T_1 with the harvest index of 86.45% during 2017, 87.07% during 2018 and 86.76% in the average of both the years. The percent increase was recorded to be 6 % in T_{13} over the control T_1. The treatment T_{13} was followed by the treatment T_{12} (92.15% in 2017, 92.54% in 2018 and 92.35% in the mean data) and the results remained at par with T_{13}. Similarly, the treatment T_{11} followed T_{12} (91.75% during 2017, 92.27% during 2018 and 92.0 % in the mean data) over the control treatment T_1 which is evident from table 4.29. Similar observations have been recorded by Kumar *et al*. (2017).

Table 4.29Effect of different treatments on harvest index of potato

Treatments*		Harvest index (%)		
		Ist year (2017-18)	2^{nd} year (2018-19)	Mean
T_1	Control	86.45	87.07	86.76
T_2	100% K_2O (RDF)	91.07	91.63	91.35
T_3	75% K_2O (RDF)	90.24	90.41	90.33
T_4	125% K_2O (RDF)	91.48	91.84	91.66
T_5	K_2O (75%) + Cu (75%) Foliar application	90.28	90.59	90.44
T_6	K_2O (75%) + Cu (100%) Foliar application	90.49	90.73	90.61
T_7	K_2O (75%) + Cu (125%) Foliar application	90.75	90.74	90.75
T_8	K_2O (100%) + Cu (75%) Foliar application	91.20	91.67	91.44
T_9	K_2O (100%) + Cu (100%) Foliar application	91.44	91.72	91.58
T_{10}	K_2O (100%) + Cu (125%) Foliar application	91.50	91.91	91.71
T_{11}	K_2O (125%) + Cu (75%) Foliar application	91.75	92.27	92.01
T_{12}	K_2O (125%) + Cu (100%) Foliar application	92.15	92.54	92.35
T_{13}	K_2O (125%) + Cu (125%) Foliar application	92.30	92.74	92.52
T_{14}	Control + Cu Foliar application	87.27	87.42	87.35
	CD	1.57	1.66	0.65

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

6.1 Economics of treatments

6.1.1 Gross Returns: The data pertaining to gross returns during the year 2017-18, 2018-19 have been shown in table 4.30, 4.31 and 4.32. A gradual increase in the gross return was observed with increased treatment combinations of potassium and copper. The application of potassium, copper and its combination recorded the maximum gross returns under the treatment T_{13} in the year 2018-19 (Rs 472186 /ha) as compared to gross returns obtained in year 2017-18 (Rs 398376/ha) and the mean gross returns of both years was reported to be Rs 435281/ha.

6.1.2 Net Returns: Statistics in table 4.28, 4.29 and 4.30 indicated that maximum net return was obtained under treatment T_{13} (Rs 377036/ ha)during the year 2018-19 as compared to year 2017-18 where maximum net returns was Rs 306726 /ha. However, the mean net returns for both years was Rs 341881/ha.

6.1.3Net Returns/rupee invested and Benefit: Cost ratio: Net returns rupee-1 invested and Benefit: Cost ratio improved consistently upon increased application of potassium, copper and its combination. Net return per rupee invested was found to be higher in the year 2018-19 under treatment T_{13} (3.96) as compared to net return per rupee invested during year 2017-18 (3.35). Likewise, B: C ratio was also found to be maximum under treatment T_{13} in year 2018-19 (4.96) as compared to 2017-18 (4.35). Higher profitability under treatment T_{13} could be explained in the light of higher tuber productivity obtained.

4.30 Effect of different treatments on Net Returns and Benefit: Cost ratio during year 2017-18

Treatments*		1st year (2017-18)			
		Gross Return (Rs ha^{-1})	Net Return (Rs ha^{-1})	Net Returns per Re invested	B:C ratio
T_1	Control	142188	57238	0.67	1.67
T_2	Recommended Dose (K_2O)	303264	212214	2.33	3.33
T_3	K_2O (75%)	247032	156382	1.73	2.73
T_4	K_2O (125%)	338400	246950	2.70	3.70
T_5	K_2O (75%) + Cu (75%) Foliar application	253176	162406	1.79	2.79
T_6	K_2O (75%) + Cu (100%) Foliar application	268728	177918	1.96	2.96
T_7	K_2O (75%) + Cu (125%) Foliar application	285084	194234	2.14	3.14
T_8	K_2O (100%) + Cu (75%) Foliar application	312120	220950	2.42	3.42
T_9	K_2O (100%) + Cu (100%) Foliar application	325116	233906	2.56	3.56
T_{10}	K_2O (100%) + Cu (125%) Foliar application	335892	244642	2.68	3.68
T_{11}	K_2O (125%) + Cu (75%) Foliar application	352308	260738	2.85	3.85
T_{12}	K_2O (125%) + Cu (100%) Foliar application	382560	290890	3.17	4.17
T_{13}	K_2O (125%) + Cu (125%) Foliar application	398376	306726	3.35	4.35
T_{14}	Control + Cu Foliar application	161268	76158	0.89	1.89

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

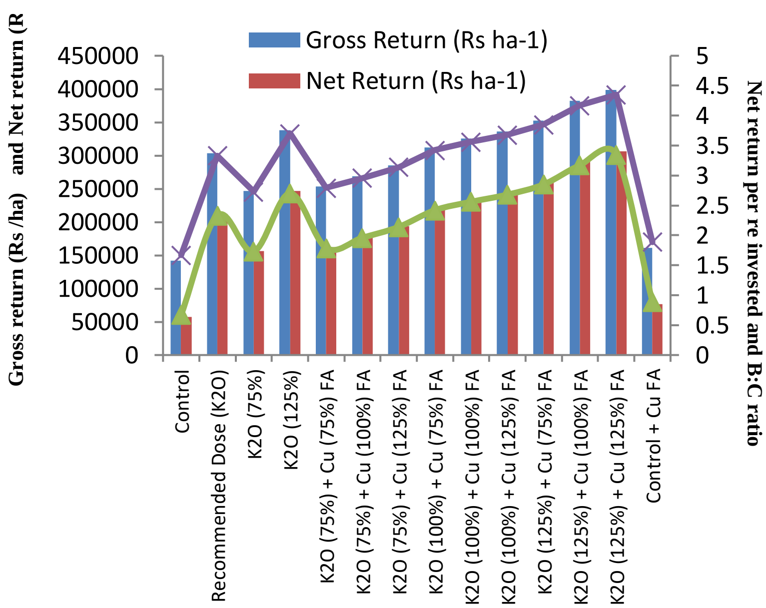

Fig. 4.6 Effect of different treatments on Net Returns and Benefit: Cost ratio during year 2017-18

Table 4.31 Effect of different treatments on Net Returns and B:C ratio during year 2018-19

Treatments*		2nd year (2018-19)			
		Gross Return (Rs ha^{-1})	Net Return (Rs ha^{-1})	Net Returns per Re invested	B:C ratio
T_1	Control	165893	77443	0.88	1.88
T_2	Recommended Dose (K_2O)	358423	263873	2.79	3.79
T_3	K_2O (75%)	284245	190095	2.02	3.02
T_4	K_2O (125%)	392444	297494	3.13	4.13
T_5	K_2O (75%) + Cu (75%) Foliar application	293683	199413	2.12	3.12
T_6	K_2O (75%) + Cu (100%) Foliar application	311792	217482	2.31	3.31
T_7	K_2O (75%) + Cu (125%) Foliar application	319657	225307	2.39	3.39
T_8	K_2O (100%) + Cu (75%) Foliar application	365586	270916	2.86	3.86
T_9	K_2O (100%) + Cu (100%) Foliar application	376064	281354	2.97	3.97
T_{10}	K_2O (100%) + Cu (125%) Foliar application	394836	300086	3.17	4.17
T_{11}	K_2O (125%) + Cu (75%) Foliar application	417378	322308	3.39	4.39
T_{12}	K_2O (125%) + Cu (100%) Foliar application	452296	357126	3.75	4.75
T_{13}	K_2O (125%) + Cu (125%) Foliar application	472186	377036	3.96	4.96
T_{14}	Control + Cu Foliar application	185198	96588	1.09	2.09

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kg ha^{-1}, K_2O@62 kg ha^{-1}. N and P doses were same in all the treatments.

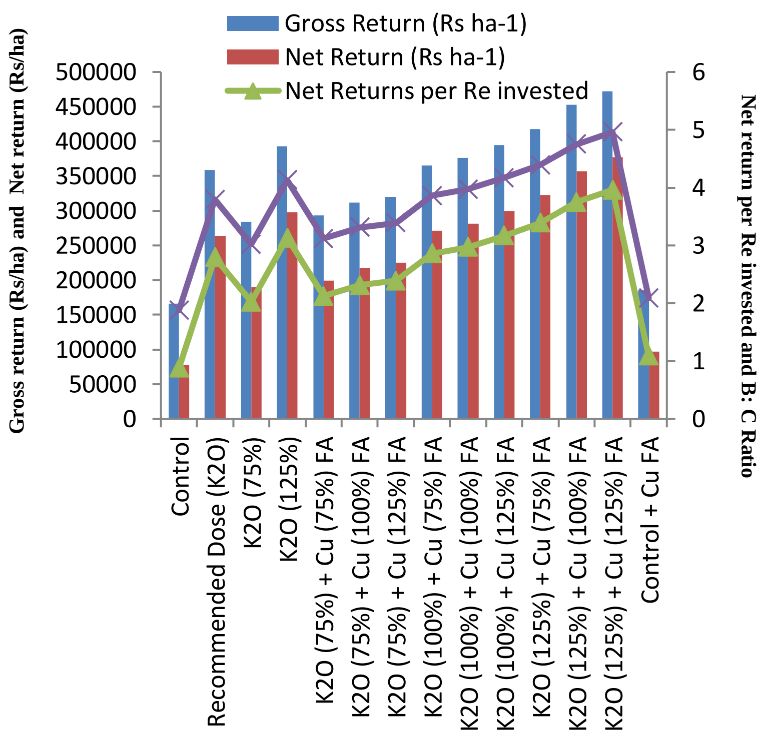

Fig. 4.7 Effect of different treatments on Net Returns and B: C ratio during year 2018-19

Table 4.32 Effect of different treatments on Net Returns and B:C ratio in Mean data

Treatments*		Mean data			
		Gross returns (Rs ha^{-1})	Net Returns (Rs ha^{-1})	Net returns per Re invested	B:C ratio
T_1	Control	154041	67341	0.78	1.78
T_2	Recommended Dose (K_2O)	330844	238044	2.57	3.57
T_3	K_2O (75%)	265639	173239	1.87	2.87
T_4	K_2O (125%)	365422	272222	2.92	3.92
T_5	K_2O (75%) + Cu (75%) Foliar application	273430	180910	1.96	2.96
T_6	K_2O (75%) + Cu (100%) Foliar application	290260	197700	2.14	3.14
T_7	K_2O (75%) + Cu (125%) Foliar application	302371	209771	2.27	3.27
T_8	K_2O (100%) + Cu (75%) Foliar application	338853	245933	2.65	3.65
T_9	K_2O (100%) + Cu (100%) Foliar application	350590	257630	2.77	3.77
T_{10}	K_2O (100%) + Cu (125%) Foliar application	365364	272364	2.93	3.93
T_{11}	K_2O (125%) + Cu (75%) Foliar application	384843	291523	3.12	4.12
T_{12}	K_2O (125%) + Cu (100%) Foliar application	417428	324008	3.47	4.47
T_{13}	K_2O (125%) + Cu (125%) Foliar application	435281	341881	3.66	4.66
T_{14}	Control + Cu Foliar application	173233	86373	0.99	1.99

* RDF = N@187kg ha^{-1}, P_2O_5 @62 kgha^{-1}, K_2O@62 kgha^{-1}. N and P doses were same in all the treatments.

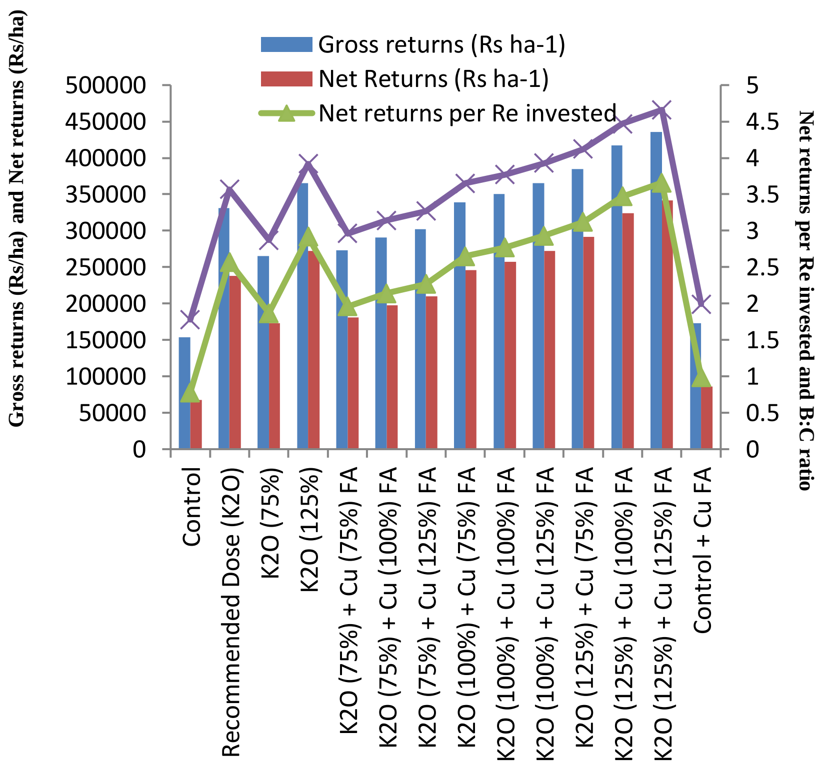

Fig. 4.8 Effect of different treatments on Net Returns and B: C ratio in Mean data

Chapter 5

Summary and Conclusion

The investigation entitled, 'Effect of potassium and copper on yield and quality of potato (*Solanum tuberosum* L) in a Typic Ustorthent soil in sub - mountain area of Punjab' was conducted during *Rabi* seasons of 2017-18 and 2018-19 at village Bhulana, Hoshiarpur (Punjab) with the subsequent aims:

1. To evaluate the effects of different levels of potassium and copper fertilizers on growth, yield and quality of potato
2. To find the optimum dose of potassium and copper fertilizers
3. To evaluate the comparative economics of different treatments

The field investigation was conducted in randomized block design, that contained fourteen different applications comprising FYM and the fertilizer dose comprised of N @187 kg per hectare, P_2O_5 @ 62 kg per hectare, K_2O @ 62 kg per hectare. The experiment was conducted with three replications. N and P doses were same in all the treatments while varied fertilizer dose of K_2O was incorporated in the soil along with copper applied @ 75%, 100% and 125% of the recommended dose as foliar spray. The significant outcomes of current experiment have been compiled as:

1. Application of potassium, copper and their combination posed insignificant effect on emergence percentage, clearly depicting the negligible impact of treatments on the potato emergence.
2. Plant height increased gradually and significantly with different treatment combinations at 30, 60 and 90 days after sowing. However, the maximum height was reported at 90 days after sowing under the treatment K_2O (125%) and Cu (125%) foliar application.
3. The fresh and dry weight increased significantly with various treatment combinations, while the maximum biomass was reported under the treatment K_2O (125%) and Cu (125%) foliar application.
4. The leaf area index expanded gradually with the advancement of the growing season under various treatment combinations. The maximum LAI was recorded on 60 DAS under the treatment K_2O (125%) and Cu (125%) foliar application, which further decreased marginally at harvest under all the treatments.
5. Application of potassium, copper and their combination posed negligible effect on number of haulms per plant.
6. Development studies i.e. days to emergence and days to maturity showed non-significant response with application of potassium, copper and their combinations.

7. Application of potassium, copper and their combinations resulted in insignificant effect on the number of plants per meter square. However, significant response of all treatment combinations were recorded for yield attributes i.e. average number of tubers per plant, average weight of tubers, average weight of tubers per plant, tuber yield and haulm yield, with maximum increase observed under the treatment K_2O (125%) and Cu (125%) foliar application.

8. The content of starch in tubers increased significantly under the application of potassium, copper and their combinations. The percent increase was recorded to be highest under the treatment K_2O (125%) and Cu (125%) foliar application.

9. A significant high content of vitamin C was found under various treatments of potassium, copper and their combinations. Highest content of vitamin C was recorded under the treatment K_2O (125%) and Cu (125%) foliar application.

10. Specific gravity increased gradually with the application of potassium, copper and their combinations. The maximum increase in the specific gravity was observed under the treatment K_2O (125%) and Cu (125%) foliar application.

11. Treatment of potassium, copper and their combinations showed significant effect on grading of potato tubers. Significantly highest 'A' and 'B' grade tuber yield was recorded with application of K_2O (125%) and Cu (125%). However, highest 'C' grade tuber yield was observed under K_2O (75%) and Cu (125%).

12. After harvest, the status of available K_2O in soil was found to be differentially affected by the treatment of potassium, copper and their combinations. The highest value of potassium was recorded under the treatment K_2O (125%) and Cu (125%) foliar application.

13. A consistent rise in the content of potassium in tubers and haulms was observed with application of potassium, copper and their combinations. The maximum increase in the potassium content was observed under the treatment K_2O (125%) and Cu (125%) foliar application.

14. Copper content increased significantly with treatment of potassium, copper and their combinations. The highest content of copper was recorded under the treatment K_2O (125%) and Cu (125%) foliar application.

15. Treatment of potassium, copper and their combinations had significant effect on the harvest index. It was recorded to be maximum under the treatment K_2O (125%) and Cu (125%) foliar application.

16. In respect of economics, application of K_2O (125%) and Cu (125%) foliar application recorded maximum gross returns, net returns, net returns rupee^{-1}invested and Benefit :Cost ratio as compared to other combination of treatments.

Conclusions

- The treatment K_2O (125%) and Cu (125%) foliar application showed positive response on potato crop in terms of growth, yield, quality and economics when compared to other treatment combinations. This dose of potassium and copper increased the plant height, photosynthetic efficiency of potato plant as depicted by increased leaf area index, leading to increased fresh and dry weight, eventually resulting in increased vitamin C, specific gravity, starch accumulation, tuber weight, yield and harvest index.
- The available potassium content of soil after harvest, potassium content in tuber and haulm and copper content in tuber also increased under the same treatment combination because of improved availability of minerals in soil, thus facilitating the plant roots to absorb higher nutrients and influencing the economics too.
- On the basis of this study, it is recommended to the farmers that they can go for application of K_2O (125%) of RDF and copper application in sandy soil. However, further adaptive research trials are needed at different location in the state of Punjab.

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Appendix – I

Fixed cost of potato cultivation (ha^{-1}) (2017-18)

Particulars	Operational input per hectare	Rate (Rs.)	Units	Total cost (Rs. ha^{-1})
1. Seed	3000 kg	15	3000	45000
2. Manures and fertilizers				
FYM	10 t	1000	10	10000
3. Ploughing	5 hr	800	5	4000
4. Labourers				
Plot preparation	8 man days	300	8	2400
Sowing	25 man days	300	25	7500
Irrigation	10 man days	300	10	3000
Harvesting	25 man days	300	25	7500
5. Spray				
Paraquat	2.0L	340	2	680
Dithane	1.8 l	400	1.8	720
Ridomill	1.8 l	1000	1.8	1800
Cypermethrin	750 ml	400	0.75	300
Copper sulphate ($CuSO_4$)				
Fipronil (Soil application)	10 kg	85	10	850
6. Spray Labourers	4 man days	300	4	1200
Cost of cultivation (Rs ha^{-1})				**84950**

Appendix – II

Treatment wise cost of cultivation (Rs ha^{-1}) (2017-18)

Treatments	Fixed Cost	Variable Cost	Total cost of cultivation
Control	84950	0	84950
Recommended Dose (K_2O)	84950	6100	91050
K_2O (75%)	84950	5700	90650
K_2O (125%)	84950	6500	91450
K_2O (75%) + Cu (75%) Foliar application	84950	5820	90770
K_2O (75%) + Cu (100%) Foliar application	84950	5860	90810
K_2O (75%) + Cu (125%) Foliar application	84950	5900	90850
K_2O (100%) + Cu (75%) Foliar application	84950	6220	91170
K_2O (100%) + Cu (100%) Foliar application	84950	6260	91210
K_2O (100%) + Cu (125%) Foliar application	84950	6300	91250
K_2O (125%) + Cu (75%) Foliar application	84950	6620	91570
K_2O (125%) + Cu (100%) Foliar application	84950	6720	91670
K_2O (125%) + Cu (125%) Foliar application	84950	6700	91650
Control + Cu Foliar application	84950	160	85110

Appendix – III

Fixed cost of potato cultivation (ha^{-1}) (2018-19)

Particulars	Operational input per hectare	Rate (Rs.)	Units	Total cost (Rs. ha^{-1})
1. Seed	3000 kg	16	3000	48000
2. Manures and fertilizers				
FYM	10 t	1000	10	10000
3. Ploughing	5 hr	850	5	4250
4. Labourers				
Plot preparation	8 man days	300	8	2400
Sowing	25 man days	300	25	7500
Irrigation	10 man days	300	10	3000
Harvesting	25 man days	300	25	7500
5. Spray				
Paraquat	2.0L	370	2	740
Dithane	1.8 l	400	1.8	720
Ridomill	1.8 l	1050	1.8	1890
Cypermethrin	750 ml	400	0.75	300
Copper sulphate ($CuSO_4$)				
Fipronil (Soil application)	10 kg	95	10	950
6. Spray Labourers	4 man days	300	4	1200
Cost of cultivation (Rs ha^{-1})				**88450**

Appendix – IV

Treatment wise cost of cultivation (Rs ha^{-1}) (2018-19)

Treatments	Fixed Cost	Variable Cost	Total cost of cultivation
Control	88450	0	88450
Recommended Dose (K_2O)	88450	6100	94550
K_2O (75%)	88450	5700	94150
K_2O (125%)	88450	6500	94950
K_2O (75%) + Cu (75%) Foliar application	88450	5820	94270
K_2O (75%) + Cu (100%) Foliar application	88450	5860	94310
K_2O (75%) + Cu (125%) Foliar application	88450	5900	94350
K_2O (100%) + Cu (75%) Foliar application	88450	6220	94670
K_2O (100%) + Cu (100%) Foliar application	88450	6260	94710
K_2O (100%) + Cu (125%) Foliar application	88450	6300	94750
K_2O (125%) + Cu (75%) Foliar application	88450	6620	95070
K_2O (125%) + Cu (100%) Foliar application	88450	6720	95170
K_2O (125%) + Cu (125%) Foliar application	88450	6700	95150
Control + Cu Foliar application	88450	160	88610

LIST OF PUBLICATIONS

1. Singh P, Kumar R and Kumar S (2021) Effect of Potassium and Copper on Yield and Quality of Potato. *Annals of Biology* **37** : 182-185

LIST OF CONFERENCES

1. National Seminar on “ Organic Farming: A way to Sustainable Development” held at DEV SAMAJ COLLEGE FOR WOMEN, Chandigarh
2. National Seminar on “ Sustainable Rural Livelihood - Opportunities and Challenges” held at G.G.D.S.D. COLLEGE, HARIANA (HOSHIARPUR)