Effect of nitrogen and sulphur on growth and yield attributes of potato (*Solanum tuberosum L.*)

Thesis

Submitted to the Lovely Professional University
in partial fulfilment of the requirements
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By

Harinder Singh
(Registration No. 11211780)

Under the supervision of
Dr. Madhu Sharma

Department of Agronomy
School of Agriculture
LOVELY PROFESSINAL UNIVERSITY
PUNJAB 144411

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CERTIFICATE

Dr. Madhu Sharma
Assistant Professor

Head of Department
School of Agriculture
Lovely Professional University
Phagwara, Punjab.

This is to certify that the thesis titled, **"Effect of nitrogen and sulphur on growth and yield attributes of potato (*Solanum tuberosum L.*)"** submitted in partial fulfilment of the requirement for the award of degree of **Master of Science (Agriculture)** in the discipline of **Agronomy** of LPU, Phagwara is a bonafide research work carried out by **Mr. Harinder Singh (Registration no.11211780)** son of S.Gurdev Singh under my supervision and that no part of this thesis has been submitted for any degree or diploma.

Place: Phagwara **(Dr. Madhu Sharma)**
Date: Major Advisor

DECLARATION

I hereby declare that thesis entitled "**Effect of nitrogen and sulphur on growth and yield attributes of potato (*Solanum tuberosum L.*)**" is an authentic record of my work carried out at Lovely Professional University in partial fulfilment of the requirement for the degree of **Master of Science (Agriculture)** in the discipline of **Agronomy**, under the guidance of Dr. Madhu Sharma, Assistant Professor, School of Agriculture and that no part of this thesis has been submitted for any degree or diploma.

(Harinder Singh)

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Harinder Singh

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LIST OF ABBREVIATIONS

@	At the rate of
ºC	Degree Celcius
i.e	Id est (that is)
CD	Critical Difference
cm	Centimetre
DAS	Days After Sowing
DAP	Days After Planting
df	Degree of freedom
et al.	et alii (and others)
g	Gram
ha	Hectare
K	Potassium
kg	kilogram
q	Quintal
m	Metre
mm	milli metre
N	Nitrogen
NS	Non Significant
P	Phosphorous
S	Sulphur
PAU	Punjab Agriculture University
LPU	Lovely Professional University
SS	Sum of squares
%	Percentage
/	Per
viz.	vi delicet (namely)
B:C	Benefit –cost ratio

Effect of nitrogen and sulphur on growth and yield attributes of potato (*Solanum tuberosum* L.)

ABSTRACT

The present investigation was carried out to study the effect of four levels of nitrogen (0,90,180,270) and three levels of sulphur (0,25,50) application on growth and yield attributes of potato at lovely professional university, Phagwara, Punjab, India during *rabi* 2013. The treatments ware replicated thrice in split plot design. The study revealed that N 180kg/ha + S 50kg/ha enhanced of a morphological and quality attributes such as plant emergence, number of shoots, periodic plant height, dry matter accumulation, leaf area index,percent reducing sugar and tuber dry matter, there by proving the role of sulphur and nitrogen in high tuber yield. Highest total and processable yield was exhibited by treatment T_9 i.e. N 180 kg/ha+S 50 kg/ha expressing the role of S in N uptake and use efficiency. Benefit cost (B:C) ratio, maximum profitability was registered under nitrogen 180 kg/ha + sulphur 50kg/ha.

Key words: Potato, sulphur, nitrogen, yield, growth, quality, benefit cost ratio

1. INTRODUCTION

Potato (*Solanum tuberosum*) is a third largest food crop of the world in terms of fresh produce after rice and wheat. It can supplement the food needs of the country in a substantial way as it produces more dry-matter, well balanced protein and calories from per unit area and time than other major food crops. The potato can be distinguished from cereals like rice and wheat for its higher capacity to produce dry matter, which is about 47.6 kg/ hectare. The problem of malnutrition and under nutrition can be largely solved if potato is accepted as a major food and not merely as a vegetable in our country. It is a nutritious food containing practically all the essential dietary constituents. Like cereals, carbohydrates are the major constituents of potato. Besides, it contains essential nutrients such as proteins and minerals like calcium, phosphorus and iron, and vitamins viz., B1, B2, B6 and C (Singh *et al.,* 2008) Potato is the native of South America and was introduced in India at the beginning of seventeenth century by Portuguese. India is the third largest producer of potatoes in world after China and Russia with a total production of 45.3 million tones from an area of 1992.2 thousand hectares(Anon.,2012-13). In Punjab, potato is cultivated on an area of 85.21 thousand hectares (5 per cent of total Indian area) with total production of 2.13 million tones which contributes 5.07 per cent in the total production of the country (Anon., 2012-13). In Punjab, primarily potato belt is confined to Doaba region i.e. Hoshiarpur, Jalandhar, Kapurthala and Nawanshehar districts. It is also grown in Amritsar, Ludhiana, Moga and Patiala districts.

In the 21st century, nutrient efficient plants play important role in increasing crop yields compared to the 20th century, mainly due to limited land and water resources available for crop production, higher cost of inorganic fertilizer inputs, declining trends in crop yields globally and increasing environmental concerns. These factors have enhanced the importance of nutrient efficient cultivars that are also higher producers (Fageria *et al*., 2008).

Potato is a perishable commodity and has short shelf life. In Punjab/north western India, Potato has to be either consumed or shifted to cold stores before hot summer months of May and June. Therefore, processing of potatoes in different forms. i.e.chips,french fries etc. seems to be a way to save the precious food.

Industry requires 40-80 mm size of potatoes, high in dry matter and low reducing sugar for quality processing. Nitrogen is valuable nutrient for plants and plays an important role in tuber size development but overdose of nitrogen lowers the tuber dry matter (Zelalem *et al*,2009). Nitrogen is one of the most essential nutrients required by plant globally. It is an integral component of many compounds such as chlorophyll, nucleotides, alkaloids, enzymes, hormones and vitamins, etc. which are essential for plant growth processes. (Brady 2012). Although N is abundant in atmosphere, yet it is the most limiting nutrient for most crops and soils. Besides being limited, this nutrient has low use efficiency as a large proportion of N applied to the soil through fertilizers get lost by way of leaching, denitrification and volatilization.

Proper level of nitrogen has an positive impact on quality and yield of potatoes. Appropriate use of nitrogen expanded the leaf area index and increases photo assimilates. (Vaezzadeh *et al.*,2010). Excessive application of nitrogen decreases starch content and also spoil the taste while cooking (Vokal and Radiel., 1996). On other hand Sulphur is one of sixteen essential nutrient elements and fourth major nutrient after NPK, required by plants for proper growth and yield as it is known to take part in many reactions in all living cells (Sud and Sharma, 2002). Sulphur deficient plants have poor utilization of nitrogen, phosphorus and potash at all age (Nasreen *et al*., 2003). Nitrogen (N) is often the most limiting factor in crop production. Hence, application of fertilizer nitrogen results in higher yields and concentration in plant tissue also increases (Jurg Blumenthal *et al.*,2008).

Intensive cropping and use of high-grade fertilizers have caused the depletion of sulphur in soils. Decrease in tuber dry matter yield particularly cystine and leucine were observed with sulphur deficiency (Eppendorfer and Eggum, 1994). Sulphur has a direct effect on soil as it may reduce pH which improves the availability of microelements such as Fe, Zn, Mn and Cu as well as crop yield and its related characteristics (Tantawy *et al*., 2009). The need of application of sulphur along with its beneficial effects on yield and quality has been reported by earlier workers (Singh *et al*., 1995).

Recently there is an increase in awareness about role of sulphur application on soil . (Bloem *et al.*,2004). Continuous removal of S from soils through plant uptake has led to widespread S deficiency and affected soil S budget (Aulakh, 2003) all over the world. Application of sulphur on onion, significantly increased the other nutrients uptake (Sankaran *et al.*,2005 and Debhi *et al.*,2004). Sulphur also have influence on potato flower by involvement in the volatile S- compound (Forney *et al.*,2010).

Therefore the present study was envisaged to determine the effect of nitrogen and sulphur on the yield and quality of potato in split plot design with following objectives:-

- To study the effect of nitrogen and sulphur on growth, yield and quality attributes of Kufri Chipsona – 3
- to study the interaction effect of nitrogen and sulphur
- to determine the best treatment on basis of benefit – cost ratio

2. REVIEW OF LITERATURE

The relevant research work carried out so far on some aspects of present investigation entitled "Effect of nitrogen and sulphur on growth and yield attributes of Potato (*Solanum tuberosum L.*)". The brief review of literature pertaining to present study in potato is presented under following headings:

2.1 Effect of nitrogen on growth and yield of potato.
2.2 Effect of sulphur on growth and yield of potato.

2.1 EFFECT OF NITROGEN ON GROWTH AND YIELD OF POTATO

Jatav *et al.*,(2013) conducted study in Central Potato Research Station , Jalandhar to determine effect of nitrogen and varieties of potato on yield and agronomic N use efficiency in north- western plains of India and revealed that different levels of nitrogen increases yield of potato. Kumar *et.al.*,(2012) reported that 270 kg N + 80 kg P + 150 kg K/ha gave optimal economic returns without effecting the processing quality of Kufri Chipsona-3 to the potato growers under west-central plain conditions of India. Singh and Lal (2012) observed during their study at Central Potato Research Station, Patna that application of nitrogen improve the tuber size and grade wise yield of potato.

Zewide *et al.*,(2012) preformed an experiment at Masha District, Southwestern Ethiopia to investigate the effect of nitrogen and phosphorus rates on yield and components of potato. They concluded that application of 165 kg N/ha significantly increased days to flowering by 6 days ,days to physiological maturity by 13 days, above ground biomass by 36 per cent underground biomass by 29.79 per cent, total tuber yield by 60.33 per cent, total tuber number by 31.7 per cent and average tuber weight by 22.43 per cent. Sandhu *et al.*,(2010) in an investigation at Amritsar found that total yield and processing grade yield increases with nitrogen application of 200 kg /ha along with dry matter content and tuber flesh firmness.

Zelalem *et al.*,(2009) conducted an experiment to determine the response of potato (*Solanum tuberosum L.*) to different rates of nitrogen (N) applied as urea (0, 69, 138 and 207 kg /ha) and phosphorus (P) (0, 20, 40 and 60 kg /ha) fertilization on Vertisols of Debre Berhan in the highlands of central Ethiopia. They revealed that application of 207 kg N/ha

delayed days to flowering and physiological maturity by four and nine days respectively, compared to the control. Similarly, it increased plant height (24 cm), above ground biomass (224.5 per cent), underground biomass (108 per cent), marketable tuber yield (175 per cent), total tuber yield (119 per cent), marketable tuber number (95.6 per cent), total tuber number (34 per cent) and average tuber weight (82 per cent) over the control. On the contrary, nitrogen fertilization significantly reduced tuber specific gravity and dry matter content without affecting stem number, unmarketable tuber yield and number, and harvest index.

Ravikant and Chadha (2008) studied the performance of potato varieties for dry matter as influenced by planting seasons and fertility regimes in mid hills of Himachal Pradesh. They reported that dry matter content and tuber yield was increased with the application of 180 kg/ha of nitrogen along with 150 kg/ha of phosphorus and potassium each.

Al-Moshileh *et al.*,(2005) observed that increasing potassium sulphate rates resulted in a significant increase in plant height, leaf area, chlorophyll concentration, specific gravity, potash concentration, carbohydrate content and marketable tuber yield. They also found that the split application of 300 kg N/ha in three equal doses gave the highest percentage of soil coverage and marketable tuber yield.

Singh (2002) observed that application of 100% P_2O_5 of the recommended dose significantly increased the tuber yield/ha. Response to phosphorus increased when either seed tubers were inoculated with *Pseudomonas striata* or crop was fertilized with nitrogen.

Adhikari (2001) assessed the growth and yield performance of two potato cultivars and obtained the highest yield of tuber 35.3 and 21.1 t/ha at 150:100:100 and 100:100:100 kg/ha NPK levels respectively. Sharma and Ezekiel (1993) observed that application of 150 kg N/ha either as basal or in splits recoded significantly higher tuber yield than 75 kg N/ha. Gupta (1992) reported that N has a significant effect on the potato yield. The total potato yield increased by 11.0 %, 88.3 % and 110.3 % with application of 60, 120,180 kg N/ha.

Bisen and Barholia (1990) found that N application at 80 kg N/ha (40 kg N at planting + 20 kg N at earthing up and 20 kg N as two foliar sprays) gives maximum significant yield of 259.56 q/ha of potato tubers followed by 120 kg N at planting. Beirne and Cassidy (1990) reported that the tuber yield increased up to 100-150 kg N/ha and remained constant thereafter; percent dry matter of tubers was significantly diminished by doses of N above 150 kg/ha.

Singh and Sharma (1987) conducted field experiments during *kharif* 1984 and 1985 at Central Potato Research Station, Shillong under acidic soils conditions. They concluded that plant height increased significantly up to 120 kg N /ha. Stems/m^2 remained unaffected by

either treatment in both years. Compound leaves and tuber numbers increased up to 180 kg/ ha , however ,significant increase in the number of tubers/m^2 was only up to the application of 60 kg N /ha. Tuber yield was observed to increase up to 120kg N /ha in Kufri Jyoti and up to 180 kg N/ ha in SS/C 562 and SS/C 1101.

Rajanna *et al.*,(1987) carried out a field trial at the University of Agricultural Sciences ,Bangalore during *rabi*,1985-1986 to study the effect of different levels of N,P_2O_5 and K_2O on growth ,yield and quality of Kufri Jyoti. They stated that the highest plant height (41.04 cm) was recorded at 160 kg N/ha. Further increase in N level did not increase the plant height and lowest was observed in the control (25.68 cm). Amongst different N levels highest yield (232.82 q/ha) was recorded at 160 kg /ha. The result revealed that the application of 160 kg N /ha was found to be optimum in sandy loam soils of Bangalore.

Satyanarayana and Arora (1985) conducted an experiment at Indian Agricultural Research Institute, New Delhi to find out the effect of nitrogen and potassium on potato variety Kufri Bahar. They revealed that 150 kg N resulted in larger size tubers, higher bulking rate and finally higher tuber yield. Nitrogen at 150 kg /ha resulted in 91.1 and 88 per cent ware size tubers in 1980-1981 and 1981-1982, respectively. Nitrogen at 150 kg/ha produced 73 per cent of total tuber yield as against 70.5 per cent due to 75 kg N/ha 60 days after planting which indicated the beneficial effect of nitrogen in the early bulking of tubers.

Kumar and Singh (1979) studied the effect of different doses of nitrogen and phosphorus on the growth and yield of potato variety Kufri Chandramukhi. They concluded that the level of nitrogen increase the height of plant. Nitrogen level 150 kg/ha showed maximum plant height (51.6 cm) and maximum yield of tubers (273.6 q/ha) as compared to other nitrogen level (0, 50, 100 and 200). But 200 kg /ha nitrogen level showed maximum average number of tuber/hill (10.5) as compared to other nitrogen levels.

2.2 EFFECT OF SULPHUR ON GROWTH AND YIELD OF POTATO

Shaheen *et al.*,(2013) reported during study at National Research Centre Nobaria that sulphur application resulted in better tuber yield along with highest nutritional value of potato tuber tissues .Leaf area, number of leaf and chlorophyll content in leaves were effected with application of sulphur in study performed by Padhi *et al.*,2013.

Sharma D.K *et.al.*, (2011) showed that sulphur application in potato has significant influence on yield and quality in terms of tuber yield , dry matter content , specific gravity ,

sugar content and starch content under malwa agro-climatic conditions of Madhya Pradesh in India. Zaman *et al.*,(2011) observed during their study at Regional Agricultural Research Station, Jamalpur that with increase in rate of sulphur application, the growth and yield also increased progressively.

Klikocka Hanna (2011) found that highest tuber yield was found when 25 kg/ha S was applied in sulphate kind and 50 kg/ha S applied in elemental kind. The yield of dry matter was highest when 25 kg/ha was applied in sulphate kind.

Alexander D. Pavlista (2010) reported that in study at U.S yield was increased by application of sulphur at 56 kg / ha. Sulphur exhibited the best growth and yield attributes in term of plant height, bulb diameter, number of leaf per plant in a study conducted by Farooqui M.A. *et.al.*,(2009). Zengin Mehmet *et.al.*,(2009) observed that Sulphur enhanced root yield of sugar beet at Konya, Turkey. Sud K.C. (2006) reported that different dose of sulphur have effect on leaf composition and tuber initiation on a sandy loam soil at Central Potato Research Institute, Shimla.

The impact of sulphur and N application on wheat productivity was evaluated at ARS Kota and Gwalior with four levels of sulphur (0, 25, 50 kg / ha S through gypsum and 10 kg/ ha S through Cosavet-DF). The yield increased with sulphur application upto 50 kg /ha. On an average, yield increased from 43.2 q /ha to 47.8 q/ ha with increase in sulphur dose from 0 to 50 kg /ha (Anon.,2005). At Uttar Pradesh application of 90 kg /ha S as gypsum gave significantly higher rice yield than application of 30 kg /ha sulphur (Ram *et al.*, 1996). Sulphur use efficiency was greater with gypsums, irrespective of their levels of application. Eppendorfer W.F. *et.al.*,(1994) proved that different rates of N,P,K and S increased soluble , insoluble and total digestible fibre from 9 to 12.4% in potatoes.

Nesressn *et al.*,(2007) observed that there was an effect of nitrogen and sulphur on the uptake of N and S by bulb, yield components, and yield of onion was observed only when they were applied together at higher rates of nitrogen (160 kg/ha) and sulphur (40kg/ha). Veerendra *et al.*,(2012) reported that application of 40 kg S/ ha recorded significantly high grain and straw yield, protein content and sulphur uptake.

Skwierawska *et al.*,(2008) found that with the application of sulphur at 40 kg/ha to 80 kg/ha there was positive effect of yield of cabbage, onion and barley, while the dose of 120 kg/ha sulphur reduced the yield of these crops .Rokhade and Bhagvantagoudra (2002) noticed that application of 40 kg sulphur per ha gave highest yield, higher dry matter in cabbage.

3. MATERIALS AND METHODS

The investigation on " Effect of nitrogen and sulphur on growth and yield attributes of potato *(Solanum tuberosum L.)* " was carried out during *Rabi* Season 2013-2014 at the Agriculture Research Field, Lovely Professional University Phagwara, (Punjab) under irrigated conditions. The experiment was conducted in Split plot Design with three replications. The PAU recommendations for agronomic practices and plant protection measures were adopted to raise a healthy crop. The details of materials used and methodology adopted during the investigation are explained as under:

3.1 Experimental site and Location

The experiment was conducted at Main Agriculture Research Field, Lovely Professional University Phagwara, Punjab, located at 31^0 15' N latitude, 75^0 41' E longitude and at an altitude of 245 m above mean sea level.

3.2 Soil and its characteristics of the experimental site

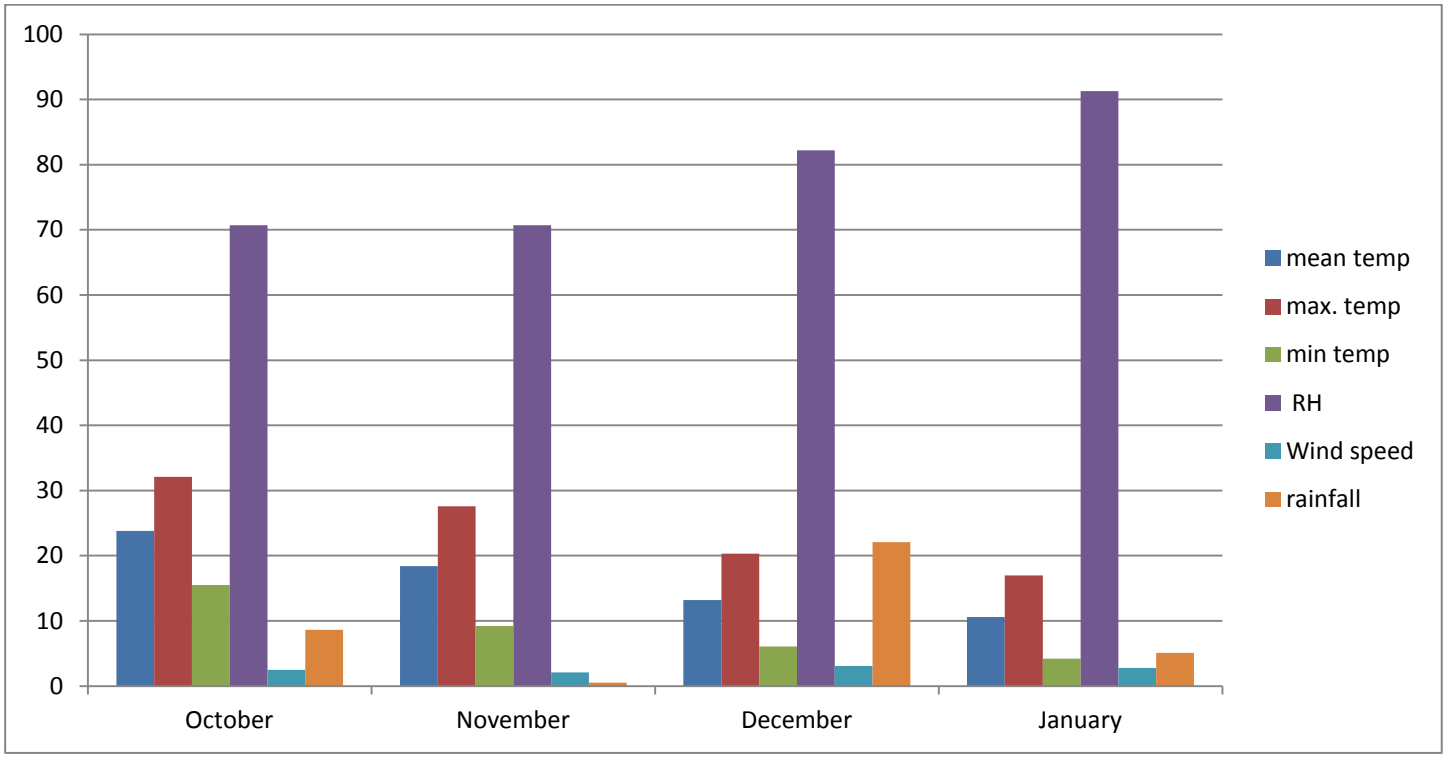
The experiment was laid out on Sandy loam soil. The composite soil sample was collected from experimental field from a depth of 0 to 30 cm before sowing and the samples were air dried, powdered and allowed to pass through 2 mm sieve and analysed for various physical and chemical properties. The data of soil analysis along with methods employed are presented in annexure I.

3.3 Climatic conditions

The experimental farm of Lovely Professional University is situated in the (PB-3) Central Zone of the State. This zone receives rainfall from both South-West and North-East monsoons which is well distributed from June to September with lower coefficient of variation.

The data on weather parameters such as rainfall (mm), mean maximum and minimum temperature (^{0}C) and relative humidity (%) recorded at Meteorological Observatory, Main Agricultural Research Station, Punjab Agricultural University of, Punjab during the experimental year and the mean are presented in annexure II.

Figure 3.1: Meteorological data (mean standard monthly values) of winter season of (2013-14) during the crop growth period



3.5 Experimental detail

3.5.1 Methodology

The experiment was laid out in a split plot design having 12 treatment and replicated thrice as fallows :

Design	Split plot Design
Replications	3
Treatment	12
Total no. of plot	36
Gross plot size	2.5 m × 1.5 m
Variety	Kufri Chipsona -3

Table 3.1 Details of experimental treatments

Treatment	Detail	Symbol
T1	Nitrogen 0kg/ha + Sulphur 0kg/ha	$N_0 + S_0$
T2	Nitrogen 0kg/ha + Sulphur 25kg/ha	$N_0 + S_{25}$
T3	Nitrogen 0kg/ha + Sulphur 50kg/ha	$N_0 + S_{50}$
T4	Nitrogen 90kg/ha + Sulphur 0kg/ha	$N_{90} + S_0$
T5	Nitrogen 90kg/ha + Sulphur 25kg/ha	$N_{90} + S_{25}$
T6	Nitrogen 90kg/ha + Sulphur 50kg/ha	$N_{90} + S_{50}$
T7	Nitrogen 180kg/ha + Sulphur 0kg/ha	$N_{180} + S_0$
T8	Nitrogen 180kg/ha + Sulphur 25kg/ha	$N_{180} + S_{25}$
T9	Nitrogen 180kg/ha + Sulphur 50kg/ha	$N_{180} + S_{50}$
T10	Nitrogen 270kg/ha + Sulphur 0kg/ha	$N_{270} + S_0$
T11	Nitrogen 270kg/ha + Sulphur 25kg/ha	$N_{270} + S_{25}$
T12	Nitrogen 270kg/ha + Sulphur 50kg/ha	$N_{270} + S_{50}$

3.6 Cultural operations

The details of the important agronomic practices followed during the experiment from seed bed preparation to the harvesting of crop are given below:

3.6.1 Land Preparation

The land was ploughed with the help of tractor by using cultivar and rotavator to get the fine tilth. The land was levelled and the field was laid out in to experimental plots as per the plan and then bunds were formed to all the plots.

3.6.2 Seed size

The tubers was sprouted with weight 30- 40 g each.

3.6.3 Seed preparation

Seed tubers ware removed from cold store 10 day prior to planting and ware spread in shade for proper sprouting. Unsprouted tubers ware removed.

3.6.4 Planting

The planting of crop was done on October 11, 2013. Seed tubers were planted by dibbling on ridges at the spacing of 60 X 20 cm. Tubers were covered with soil after planting with help of spade.

3.6.5 Weeding

Experimental plot was kept free from weeds in the experiment throughout the crop growth period by hand weeding at 20, 30 45, 60 DAS.

3.6.6 Earthing up.

Earthing up was done at 45 DAS when potato plants were 12 – 18 cm high , accompanied by application of remaining dose of nitrogenous fertilizer and cover it with soil to make a ridge thick with help of narrow spade.

3.6.7 Fertilizer application

Recommended dose of N, P and K (180:60:120 kg N, P2O5 and K2O ha-1) were applied. Full dose of ‘P’ and ‘K’ were applied along with 50 per cent of N at the time of planting. The remaining 50 per cent N was applied at time of earthing up. Full dose of sulphur according to different treatment were applied at time of planting.

3.6.8 Irrigation

First was given before seed bed preparation and next irrigation after a week. These two irrigations were applied before crop emergence, subsequent irrigation were applied as and when required throughout the growing season.

3.8.7 Plant protection measures

To protect the crop from insects, pests and disease recommended spray schedule was adopted.

Insecticides/Fungicides	Doses per acre	Date of spray
Indofil M -45	0.5 kg	15 -11-2013
Indofil M -45	0.5 kg	5 – 11-2013

3.8.8 Tagging of plants

Five plants from each plot were randomly selected and tagged for recording different observations.

3.8.9 Harvesting

Digging of potatoes was done manually on January 23, 2014.

3.9 EXPERIMENTAL OBSERVATIONS RECORDED

Development study of different plants parts during the growth period helped to explain the effect of various treatments on the final yield. Thus to assess the effect of various treatments, different plant characters were studied as mentioned below:

3.10 GROWTH CHARACTERS

3.10.1 Days taken to tuber emergence (50% and 100% emergence)

The emergence of potato seedlings from each plot was recorded on alternative day, starting from the day when sprouting start emerging above ground, and days taken to complete 50% and 100% emergence were counted for each treatment.

3.10.2 Number of shoots (60 DAS)

The no. of shoots emerged from the tubers were counted in a one row length from each plot and the plants data was recorded on five selected plants.

3.10.3 Periodic plant height (cm)

Height of five randomly selected and tagged plants from each plot were measured at 30, 60 and 90 DAS. Height of tallest shoot of the selected plant was measured from the base of the plant to top most unfolded leaf. Then average values were worked out.

3.10.4. Leaf area index (LAI)

Fresh detached leaves from the randomly selected plants were taken; leaf area index was recorded at 60 DAS with the leaf area meter.

$$\text{Leaf area index (LAI)} = \frac{\text{Leaf area (cm)}^2}{\text{Ground area (cm)}^2}$$

3.10.5 Dry matter accumulation

Dry matter was recorded from the randomly selected plants and then mean values were worked out.

3.11 YIELD ATTRIBUTES

3.11.1 Number of tuber per plant

The number of tubers per plant ware calculated from same five randomly selected plants meant for plant height and number of stems per hill in each plot. The average values were worked out at harvest time.

3.11.2 Total tuber yield (q/ha) and tuber size grading.

Total tuber yield was calculated separately from each net plot for computation of yield in q/ha. The yield was separated into 3 grades on basis of diameter as fallows:

Table 3.2 Different grades of potato

S no.	Diameter	Grade
1	Above 80 mm	Large
2	Between 80 mm – 40 mm	Medium
3	Below 40 mm	Small

3.11.3 Processable yield (q/ha)

Tuber diameter between 40mm to 80mm is considered as processable tuber. these are sorted out after harvest with help of vernier caliper. Then there average weight is calculated as per different treatments.

3.11.4 Non processable yield (q/ha)

The tubers below 40mm and above 80 mm is consider as non processable.

Non processable yield = Total yield – Processable yield

Plate 3.1 Crop growth at 30 DAS

Plate 3.2 Crop growth at 60 DAS

Plate 3.3 Plant growth in T9 at 40 DAS

Plate 3.4 Plant height in T9 at 60 DAS

Plate 3.5 Variations in tubers.

3.12 QUALITY CHARACTERS

3.12.1 Tuber dry matter accumulation (g)

Tuber dry matter accumulation was done at 60DAS, and 90DAS and was determined by oven drying 50g finely chopped and mixed tuber pieces at 65^0C till constant weight.

3.12.2 Per cent reducing sugar

Reducing sugars were estimated by Nelson-Somogi method (Pearson, 1976).

Principle

The reducing sugars when heated with alkaline copper tartrate reduce the copper from the cupic to cuprous state and thus cuprous oxide is formed when cuprous oxide is treated with arsenomolybdic acid, the reduction of molybdic acid to molybdenum blue take place. The blue colour developed is compared with a st of standards in colorimeter at 620 nm

Materials

Alkaline Copper tartrate

A. Dissolve 2.5g anhydrous sodium carbonate, 2g sodium bicarbonate, 2.5g potassium sodium tartrate and 20g anhydrous sodium sulphate in 80mL water and make up to 100ml
B. Dissole 15g copper sulphate in a small volume of distilled water. Add one drop of sulphuric acid and make up to 100ml.

Mix 4mL of B and 96ml solution A before use.

Arsenomolybdate Reagent: Dissole 2.5g ammonium molybdate in 45mL water. Add 2.5ml Sulphuric acid and mix well. Then add 0.3g disodium hydrogen arsenate dissolved in 25 ml water. Mix well and incubate at 37^0C for 24 to 48 hours.

Standard Glucose Solution: Stock: 100mg in 100mL distilled water.

Working Standard: 10mL of stock diluted to 100mLwith distilled water

Procedure

1. Weigh 100mg of the sample and extract sugars with hot 80% ethanol twice.
2. Collect the supernatant and evaporate it by keeping it on a hot water bath at 80^oC
3. Add 10mL water and dissolve the sugars
4. Pipette out aliquots of 0.1 or 0.2mL to separate test tube.
5. Pipette out 0.2, 0.4, 0.6, 0.8 and 1mL of the working standard solution into a series of test tubes.
6. Make up the volume in both sample and standard tubes to 2mLwith distilled water.

7. Pipette out 2mL distilled water in a separate tube to set a blank.
8. Add 1mLof alkaline copper tartrate reagent to each tube.
9. Place the tubes in a boiling water for 10 minutes.
10. Cool the tubes and add 1mL of arsenomolybolic acid reagent to all the tubes.
11. Make up the volume in each tube to 10mL with water.
12. Read the absorbance of blue colour at 620 nm after 10 min.

Calculation

Absorbance corresponds to 0.1mL of test = *x* mg of glucose

10mL contains = *x*/0.1 * 10 mg of glucose

= % of reducing sugars

3.13 ECONOMICS

The gross monetary returns in rupees per hectare were worked out on the basis of potato yield The prevailing market price of potato was considered.

3.13.1 Gross returns (Rs. /ha)

The gross returns were calculated by considering the prices of potato at the time of harvest.

Gross returns = Yield according to grades X Market price according to grade

3.13.2 Net returns (Rs/ha)

The net returns was calculated by deducting the cost of cultivation from the gross returns.

Net returns (Rs.) = Gross income – Total cost of cultivation

The benefit cost ratio was calculated as follows;

$$\text{B:C ratio} = \frac{\text{Gross returns (Rs./ha)}}{\text{Cost of cultivation (Rs. /ha)}}$$

3.15 STATISTICAL ANALYSIS

Statistical analysis of the data recorded was done as per split plot design (Cochran and Cox, 1963), using software developed by the department of Mathematics and statistics PAU, Ludhiana.

4. RESULTS AND DISCUSSION

The results obtained from the observations recorded for plant growth, yield and quality parameters of present study entitled, **"**Effect of nitrogen and sulphur on growth and yield attributes of potato (*Solanum tuberosum* L.)**"** conducted during *rabi* 2013-14 at the departmental Farm of School of Agriculture, LPU, Phagwara are presented and discussed here as under.

4.1 GROWTH ANALYSIS

4.1.1. Plant emergence:

A good and uniform emergence is the basic requirement for good establishment that is required for the successful raising of any crop, which ultimately determines the crop yield. Taking in view the dominant role of the plant emergence, observations on this parameter were recorded in different treatments. The data in table (4.1) reveals that different treatment have insignificant effect on emergence. It means that there was almost similar level of plant population in all the treatment. This may be due to the fact that growing seedlings get their food from the tuber. Kumar *et al* (2011) also reported that N application had insignificant effect on plant emergence under their conditions.

4.1.2 No. of shoots (80 DAS)

Number of shoots per plant or per unit area is an index of growth and adaptability of the plant to the soil and climatic condition. It is the most important parameter which has a direct bearing on development of potato yield. The data recorded on the number of shoots (80 DAS) are given in table (4.1). The data revealed that treatment T_9 (Nitrogen 180kg N and Sulphur 50kg/ha) gave significantly maximum number of shoots. Number of shoots in T_3,t_6,T_7 and T_{12} were statiscally at par to each other but significantly lower than $T_{11.}$ T_{10} is significantly superior over T_4, T_5 and T_8. On the other hand the treatment T_1 results minimum number of shoots. This might be due to the fact that fertilization application encouraged more number of independent stems. The results are in consonance with those of Zamil *et al.*,(2009) who reported that the highest number of stems per hill (4.43) obtained when the highest rate of nitrogen (254 kg/ha) was applied and the lowest (2.70) was found in the control with their genetic material under their conditions.

4.1.3 Periodic plant height (cm)

Plant height is an important physiological parameter related to growth and general development of the crop. It indicates the vigour, strength and adaptability of the crop to the existing environmental conditions. The plant height was measured from the cotyledonary node up to the growing tip at 40, 60 and 80 DAS and the mean was worked out from three plants, which were selected at randomly in each treatment and expressed in cm. The perusal of the data depicted in the table (4.1) revealed that there is a periodic increase in plant height and it differ significantly among all the treatments.

After 40 days maximum plant height (40.7) was recorded in treatment $T_{9,}$ which was statiscally at par with $T_{12.}$ T_6 was also at par with T_8 and T_{10} whereas, T_1 (33) recorded minimum plant height.

After 60 days highest plant height (59.8) was recorded in treatment T_9, which was at par with T_{12}. Minimum plant height (50) was recorded in the control.

After 80 days T_9 gave significantly higher plant height (65.5) which was superior to all the treatments. Treatment T_1 recorded the lowest plant height (58.7). The results further revealed that plant height significantly differ among all treatments.

The probable reason for increasing plant height might be due to more uptake of N during growth period resulting in increase in cell size, elongation and enhancement of cell division which ultimately increase the plant growth. Singh and Gupta (2005) found that the application of 100% N of recommended dose significantly increased the plant height with their genetic material under their conditions. The results are further supported by Rajanna *et al* (1987) who stated that application of N up to 240 kg/ha significantly increase the plant height.

4.1.4 Dry matter accumulation

Dry matter accumulation is good growth index to express the photosynthetic efficiency of the plant. It serves as a reliable measure of the relative influence of different treatments on plant growth and ultimately yield. Rate of dry matter accumulation varies across life cycle of crop. Dry weight was recorded separately at each stage of crop growth to assess dry matter accumulation in different parts and total dry matter production was expressed in g per plant. The dry matter accumulation was measured at 40, 60 and 80 DAS and the mean was worked out from five plants, which were selected at randomly in each treatment. The perusal of the data depicted in the table (4.1) revealed that dry matter accumulation increased and differed significantly in all the treatments.

Table 4.1 Effect of nitrogen and sulphur on morphological characters of potato.

Treatment	Days taken to 50%emergence	Days taken to100% emergence	No. of shoots 80 DAS	Dry Matter			Leaf area index 60DAS	Plant height		
				40 DAS	60DAS	80DAS		40 DAS	60DAS	80DAS
$N_o + S_0$	5.75	9.85	2.7	7.73	68.56	100.06	1.17	33	50	58.7
$N_O + S_{25}$	5.58	9.58	2.7	9.26	69.53	102.73	1.45	34.7	50.3	58.9
$N_o + S_{50}$	4.50	8.58	3.2	9.86	70.63	104.7	2.34	36.5	52.6	59.8
$N_{90} + S_0$	5.18	9.25	3	11.2	70.33	100.4	3.71	36.8	52.6	58.4
$N_{90} + S_{25}$	4.90	9.0	3	11.7	71.46	101.7	3.81	36	53.6	60.2
$N_{90} + S_{50}$	4.58	8.90	3.2	12	72.6	103.73	3.95	38.4	55.8	61.8
$N_{180} + S_0$	5.50	9.33	3.2	12.43	71.46	100.76	4.04	38	52	60.4
$N_{180} + S_{25}$	5.0	8.90	3	12.7	73.06	106.4	4.15	38.5	56.2	63.5
$N_{180} + S_{50}$	4.93	8.83	4.4	12.96	74.1	110.53	5.12	40.7	59.8	65.5
$N_{270} + S_o$	4.85	8.60	3.4	13.56	71.5	103.7	4.06	38.5	56.9	63.5
$N_{270} + S_{25}$	5.25	9.10	4	14.06	74.7	107.53	4.45	38.9	58.4	65.1
$N_{270} + S_{50}$	5.02	8.70	3.3	15	75.63	109.14	5.04	39.8	59.2	64.4
C.D 5 % Main	NS	NS	0.55	0.86	0.65	0.78	0.46	0.5	NS	0.67
Sub	NS	NS	0.64	0.38	0.4	0.47	0.5	0.36	NS	0.28
Main X Sub	NS	NS	NS	NS	0.8	0.95	NS	NS	NS	0.56

After 40 days dry matter accumulation (1.24) was recorded significantly higher in treatment $T_{9,}$ followed by T_{12} which was statiscally at par with T_{11} and T_{10}. Treatment T_1 (0.68) recorded minimum dry matter accumulation.

After 60 days highest dry matter accumulation (6.60) was recorded in treatment T_9, which is at par with T_{12}. Minimum dry matter accumulation (4.34) was recorded in control plot treatment.

After 80 days T_3 gave significantly highest dry matter accumulation (8.02). Treatment T_1 gave lowest dry matter (6.05).

The results are further supported by Sandhu *et al.,* (2010) who stated that application of N up to 200kg/ha significantly increase the dry matter content with their genetic material under their conditions.

4.1.5 Leaf area index

The assimilating capacity of a crop depends upon the development and maintenance of optimum LAI. LAI below optimum limits results in lesser interception of solar radiation and hence lesser production. If LAI is above the optimum limits, there is mutual shading of leaves, causing lower leaves to be parasitic. The data of leaf area index was recorded in cm^2 at 60 days after sowing. The data is presented in Table 4.1

After 60 days highest leaf area index (5.12) was recorded in treatment T_9, which was at par with T_{12}. Whereas, minimum dry matter accumulation (1.17) occurred in control plot treatment. Amir *et al.,* (2013) reported that application of N fertilizer give significantly higher leaf area index with their genetic material under their conditions.

4.2 YIELD STUDIES

4.2.1 Number of tuber per plant

It is one of the most important characters, which has a direct relationship with the ultimate yield of potato crop. The data on number of tuber at harvest were recorded. The number of tubers produced ware counted from five randomly selected plants and the mean was worked out.

The data pertaining to this character are tabulated in table (4.2) reveals that maximum number of tubers per plant was given by T_9 (7.6) which is statiscally at par with T_{11}. T_{11} is also at par with T_2, T_3, T_5, T_6,T_8,T_{10} and T_{12}. T_{11} is significantly superior to T_4 and T_7. Data indicated that all the main plot and sub plot treatments were found significantly higher than T1 (control). The number of tubers per plant differed significantly among different treatments. Roy and Jaiswal (1998) reported significantly increase in number of tubers per plant with increase in N dose with their genetic material under their conditions.

4.2.2 Grade wise tuber yield (q/ha)

Tubers collected from each of the experimental treatment plots were hand graded into large, medium and small sized tubers. Weight of tubers of each grade and total yield are presented in table (4.2).

4.2.3 Large sized tubers (>80mm diameter)

Yield of large size tubers was recorded significantly higher in T_9 (61.02) than all other treatments. T_{12} and T_8 were found statistically at par but significantly higher than T_5 and T_6.

4.2.4 Medium sized tubers (between 40-80mm diameter)

Data in table (4.2) reveals that the proportion of medium sized tubers were significantly higher in treatment T_9 (133.06) as compared to other treatments. T_{12}, T_8 ,T_6, T_{11} and T_7 were found statistically at par but significantly higher than T_5, T_4, T_3,T_2 and T_1. T_4 and T_3 were found statistically at par but significantly higher than T_1. All the treatments were found significantly higher than T_1 (control).

4.2.5 Small sized tubers (<40mm diameter)

Data in table (4.2) reveals that higher yield of small sized tubers was recorded with T_9 (51.92) which was significantly higher than all other treatments. T_8, T_{10}, T_{11} and T_{12} were observed at par but significantly higher than T_3, T_2 and T_1. T_3 and T_4 were also found at par but significantly higher than T_6.Bhardwaj *et al.*,(2008) also found significant difference among different genotypes for grade wise tuber yield with their germplasm under their conditions.

4.2.6 Total yield (q/ha)

Yield of a crop is the final result of successful completion of growth and development of its individual plant which in turn, depends upon rate of carbon assimilation and converts into harvestable products. The ultimate objective in almost all the agronomic studies is obtaining the optimum yield of a crop. The data on the effect of different fertilizer treatments on total tuber yield of potato are therefore, presented in table (4.2).

Highest total yield was recorded in T_9, which was at par with T_8, T_{12} and $T_{11,}$ where as minimum total yield was reported in control plot treatment. These results are in line with Sud and Sharma (2002) who reported that increase in tuber yield with increasing sulphur levels may be attributed to its role in better partitioning of the photosynthates in the shoot and tubers. Similarly, Lalitha *et al.*,(2002) have also reported significant effect on grade wise tuber yield and increase in bulking rate with sulphur application with their genetic material under their conditions.

Tuber yield is influenced to great degree by growth, nutrient and moisture supply N forms the constituents of chlorophyll and increases the canopy of plants and hence more photosynthesis. The N is also a part of amino acids and proteins and takes part in cell division and enlargement thereby, increasing the weight of individual potato tuber and ultimately yield. The increase in yield with the application of recommended doses of NPK by fertilizers and FYM could be attributed to corresponding increase in leaf area, which is responsible for synthesizing photosynthates and increase in number and weight of tubers as reported by Shah and Ismail (1983). Rajanna *et al.*,(1987) also reported application of different levels of N increase the tuber yield significantly over control with their genetic material under their conditions.

4.2.7 Processable yield (q/ha)

Processing industry requires 40-80 mm size of potatoes. Those size in between this range are consider fit for purpose of processing. Results in table (4.2) revealed that T_9 have highest processable yield whereas,T_8 and T_{12} were statistically at par to each other . All the treatments were found significantly higher then T_1(control).

4.2.8 Non processable yield (q/ha)

The data in table (4.2) revealed that treatment T_{10} gave the highest non processable yield. Treatment T_7 was found statistically at par with T_{11} and $T_{12.}$

Table 4.2 Effect of nitrogen and sulphur on yield and quality attributes of potato.

Treatment	No. of tubers per plant	Grade wise yield (q/ha)			Total yield (q/ha)	Dry Matter (g/plant)		Percent reducing sugar	Processable yield (q/ha)	Non-processable yield(q/ha)
		Large	Medium	Small		60 DAS	90 DAS			
$N_o + S_0$	5.3	50.67	68.45	45.04	164.16	17.85	40.16	0.31	96.46	67.7
$N_O + S_{25}$	6.6	55.9	85.78	42.22	182.9	18.19	41.11	0.32	107.8	75.1
$N_o + S_{50}$	6.7	51.22	98.23	44.95	194.4	19.12	42.07	0.31	112.1	82.3
$N_{90} + S_0$	5.6	58.33	71.53	44.81	174.4	28.02	67.28	0.31	104.86	69.56
$N_{90} + S_{25}$	6	44.64	117.3	41.84	203.8	32.93	70.09	0.33	135.06	68.76
$N_{90} + S_{50}$	6.3	45.22	129.34	40.58	215.3	36.44	70.41	0.33	142.6	72.73
$N_{180} + S_0$	5.6	54.97	124.87	45.04	224.7	35.15	71.26	0.32	108.66	116.06
$N_{180} + S_{25}$	6.6	57.68	128.58	50.56	236.5	37.33	76.88	0.34	151.53	85
$N_{180} + S_{50}$	7.6	61.02	133.06	51.92	246	41.72	80.15	0.37	160.6	85.4
$N_{270} + S_o$	6.6	53.04	125.45	50.55	229.3	34.08	71.85	0.31	110.73	118.63
$N_{270} + S_{25}$	7	55.01	126.32	52.23	233.5	36.63	72.4	0.33	140.8	92.73
$N_{270} + S_{50}$	6.6	57.7	129.58	50.62	237.9	41.15	76.12	0.32	149.56	88.36
C.D 5 % Main	NS	3.72	4.63	4.94	4.49	1.96	2.64	0.0116	3.085	4.96
Sub	0.70	2.03	1.24	2.26	1.46	0.71	1.12	0.0104	1.487	2.26
Main X Sub	NS	1.67	2.65	2.34	2.93	1.43	2.25	0.0207	2.974	4.52

4.3 QUALITY PARAMETERS

4.3.1 Dry matter accumulation of tubers (g/plant)

Dry matter accumulation by tubers is an important growth characteristic in potato which ultimately affects yield of the crop. Data on dry matter accumulation by tubers were recorded at 60 and 90 DAS.

The data are presented in table (4.2) which revealed that after 60 days, maximum tuber dry matter was observed in T_9 (41.72 g/plant) and differ significantly from all other treatments. The minimum tuber dry matter was recorded in T_1(17.85).

Maximum dry matter accumulation in tubers after 90 days was observed in T_9 (80.15 g/plant) followed by T_{12}, T_{11} and T_8 whereas, T_5 and T_6 were at par to each other but significantly higher than T_2 and T_1. Treatment T_1 give minimum tuber dry matter accumulation.

The data clearly reveal that application of nutrients at different doses of nitrogen and sulphur significantly influenced the dry weight.

As above given discussion show that there is an increasing trend in dry matter accumulation up to 90 days. Due to high LAI, the crop under this treatment might be able to intercept relatively higher solar energy resulting in increased dry matter production in all the plant parts. Sharma *et al.*,(2012) and Lei *et al.*,(2012) reported that application of N fertilizer and sulphur can significantly influence the dry matter accumulation of potato tubers with their genetic material under their conditions.

4.3.2 Per cent reducing sugar

Per cent reducing sugar was found maximum and significantly higher in T_9 treatment as compared to all other treatments. Reducing sugar content in treatment T_9 (0.37) was statistically at par to treatment T_8 . Data table (4.2) further revealed that treatment T_4 (0.31) along with T_3 (0.33) and T_1 (0.33) had the minimum reducing sugar. These results were in consonance to the findings of Raghav *et al.,* (2007) with their genetic material under their conditions.

Table 4.3: Economic analysis (in Rs/ha) of nitrogen and sulphur for potato crop .

Treat-ments	Land Rent (Rs./ha)	Seed bed preparation (Rs./ha)	Labour (Rs./ha)	Harvesting labour (Rs./ha)	Seed (Rs./ha)	Manure and Fertilizer (Rs./ha)	Total input cost (Rs/ha)	Total income (Rs/ha)	Net income (Rs/ha)	B:C ratio
T_1	25,000	4000	2300	8250	16,000	0.00	55,550	89,206.5	33,656.5	1.60
T_2	25,000	4000	2300	8250	16,000	3,279.2	58,829.2	1,01,212.0	42,382.8	1.72
T_3	25,000	4000	2300	8250	16,000	4,579.2	60129.2	1,07,336.5	47,207.3	1.78
T_4	25,000	4000	2300	8250	16,000	2,198.8	57,748.8	95,164.00	37,415.2	1.64
T_5	25,000	4000	2300	8250	16,000	3,498.8	59,048.8	1,13,760.00	54,711.2	1.92
T_6	25,000	4000	2300	8250	16,000	4798.8	60,348.8	1,20.736.00	60,387.2	2.00
T_7	25,000	4000	2300	8250	16,000	2,418.4	57,968.4	1,25,423.5	67,455.1	2.16
T_8	25,000	4000	2300	8250	16,000	3,718.4	59,268.4	1,31,624.00	72,355.6	2.22
T_9	25,000	4000	2300	8250	16,000	5,018.4	60,568.4	1,36,761.00	76,192.6	2.25
T_{10}	25,000	4000	2300	8250	16,000	2.638.0	58,188.0	1,27,189.5	69,001.0	2.18
T_{11}	25,000	4000	2300	8250	16,000	3,938.0	59,488.0	1,29,551.00	70,063.0	2.17
T_{12}	25,000	4000	2300	8250	16,000	5,238.0	60,788.0	1,32,262.00	71,474.0	2.17

1. Selling Cost of one kg of potato, small size = 4.5 Rs/kg , medium size = 6 Rs/kg , large size = 5.5 Rs/kg
2. Cost of fertilizers
   Nitrogen = 2.44 Rs/kg, Phosphorus = 11.07 Rs/kg, Potash = 10.96 Rs/kg, Sulphur = 52 Rs/kg

4.4. ECONOMIC ANALYSIS

Economic analysis of using different levels of nitrogen and sulphur for potato crop was determined by total input cost, total income and net income in Rs/ha. In data table (4.3) total cost was determined by adding all six classes (Land rent, seed bed preparation, labour, harvesting labour, seed, manure and fertilizer). Total income was calculated by multiplying total yield with marketable price of potato crop. Net income was also found out by reducing total cost from total income.

Data in table 4.3 revealed that treatment T_9 gave the maximum income followed by T_8, T_{12}, T_{11}, T_{10}, T_7 and T_6. The benefit cost ratio was found maximum in treatment T_9 followed by T_8, T_{10}, T_{12}, T_{11}, T_7 and T_6 whereas control (T_1) recorded minimum benefit cost ratio. Data showed that all treatments gave benefit cost ratio above 1, but application of 180 kg/ha of N and 50 kg/ha of S recorded highest net income and benefit cost ratio. Raghav *et al.*,(2007) observed that there was significantly effect on net income by using of organic and inorganic manures with their genetic material under their conditions

5. SUMMARY AND CONCLUSION

Field studies entitled, **"**Effect of nitrogen and sulphur on growth and yield attributes of potato (*Solanum tuberosum L.*)**"** was conducted during *rabi* 2013 at the departmental Farm, School of Agriculture, LPU, Phagwara. The experiment was laid out in split plot design with 12 treatments of nitrogen as main plot and sulphur as sub plot along with absolute control, replicated thrice for different traits viz., plant emergence, number of shoots, periodic plant height, dry matter accumulation, leaf area index, number of tubers per plant, grade wise yield, total yield, processable yield, non processable yield, percent reducing sugar, tuber dry matter, net returns and benefit cost ratio.

Analysis of variance revealed significant difference for total and processable yield and other component traits. T_9 encompassing of N_{180}+S_{50} exhibited highest number of shoots, plant height, dry matter accumulation, leaf area index, number of tubers per plant, grade wise yield, total yield, processable yield, non processable yield, percent reducing sugar, tuber dry matter. Treatment T_8 (N_{180} + S_{25}) revealed the same trend in yield and its component traits but lesser than T_9(N_{180} +S_{50}).

On the contrary, control (T_1) exhibited the lowest value for all the morphological, quality and yield traits viz., number of shoots, plant height, dry matter accumulation, leaf area index, number of tubers per plant, grade wise yield, total yield, processable yield, non processable yield, percent reducing sugar, tuber dry matter.

In term of economics, crop grown under treatment T_9 (N_{180} +S_{50}) gave higher total income and net income as compared with other treatments. Benefit cost ratio was significantly higher in T_9 than other treatments expressing importance of nitrogen and sulphur in enhancing yield and economic returns.

CONCLUSIONS

From present study, following conclusions can be drawn:

1. Significant differences existed between the treatments.
2. Highest total and processable yield was exhibited by treatment T_9 i.e. N 180 kg/ha+S 50 kg/ha expressing the role of S in N uptake.
3. Enhancement of a morphological and quality attributes such as plant emergence, number of shoots, periodic plant height, dry matter accumulation, leaf area index, and percent reducing sugar and tuber dry matter proved the role of S in N use efficiency.
4. The estimates of benefit cost ratio also concluded nitrogen 180kg/ha + sulphur 50 kg/ha to be the best dose for recommendation.

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Annexure I

Soil physico-chemical properties of the experimental field soil.

Soil Property	**Soil Depth (cm)**		**Rating**	**Method used**
Mechanical Analysis	**0-15**	**15-30**		
Sand (%)	74.2	68.8		International Pipette method (Piper, 1966)
Silt (%)	13.2	15.1		
Clay (%)	12.1	14.8		
Texture Class			Sandy loam	
Chemical Analysis				
Electrical conductivity at 25^0C (mhos cm^{-2})	0.3	0.25	Normal	In 1:2 soil : water suspension with solution bridge conductivity meter (Jackson and Prihar 1967)
pH	7.6	7.8	Normal	Beckman's pH meter using glass electrode in 1:2 soil: water suspension (Jackson and Prihar 1967)
Organic carbon (%)	0.36	0.46	Low	Walkley and Black's rapid titration method (Piper, 1966)
Available N (kg/ha)	160	156	Low	Modified alkaline potassium permanganate method (Subbiah and Asija, 1956)
Available P (kg/ha)	25.5	28.9	High	0.5 N Sodium bicarbonate extractable P by Olsen's method (Olsen *et al.*, 1954)
Available K (kg/ha)	330	356	High	1 N Ammonium acetate extractable K (Jackson and Parihar, 1967)

Annexure II

Meteorological data (mean standard monthly values) of winter season of (2013-14) during the crop growth period was recorded.

Month	Mean Temperature (^{o}C)	Temperature Maximum (^{o}C)	Temperature Minimum (^{o}C)	Relative Humidity (%)	Wind Speed (km/hr)	Rainfall (mm)
October	23.8	32.1	15.5	70.7	2.5	8.64
November	18.4	27.6	9.2	70.7	2.1	0.51
December	13.2	20.3	6.1	82.2	3.1	22.1
January	10.6	17.0	4.2	91.3	2.8	5.08

BRIEF BIODATA OF STUDENT

Title of the Thesis	Effect of nitrogen and sulphur on growth and yield attributes of potato (*Solanum tuberosum L.*)

Name of the student	Mr. Harinder Singh
Father's name	S. Gurdev Singh
Mother's name	Smt. Jasbir Kaur
Nationality	Indian
Date of birth	13 – Oct- 1989
Permanent home address	House no. 6, Professor Colony Near R.S.D. College Ferozepur City, Punjab Mobile +91 9915050775 Email: harinders.1989@gmail.com

EDUCATIONAL QUALIFICATIOIN

Degree/ Certificate	**Institution**	**Year**	**CGPA/Percentage**
B.Sc (Agriculture)	Brijindra College Faridkot	2012	63 %
Senior Secondary Certificate	Ram Sukh Das College Ferozepur	2007	63 %
Higher Secondary Certificate	Khalsa Public School Ferozepur	2005	70 %

REFERENCES

Dr Madhu Sharma Head of Department
School of Agriculture
Lovely Professional University

PLACE: Phagwara
DATE: (**Harinder Singh**)