EFFECT OF PHOSPHORUS AND POTASSIUM FERTILIZATION LEVEL ON THE GROWTH AND YIELD OF SOYBEAN

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EFFECT OF PHOSPHORUS AND POTASSIUM FERTILIZATION LEVEL ON THE GROWTH AND YIELD OF SOYBEAN

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CERTIFICATE

This is to certify that the thesis entitled **" EFFECT OF PHOSPHORUS AND POTASSIUM FERTILIZATION LEVEL ON THE GROWTH AND YIELD OF SOYBEAN"** submitted to the Faculty of Agriculture**,** Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (MS)** in **AGRONOMY,** embodies the results of a piece of bona fide research work carried out by **MAHFUJA KHANAM** Registration. No. **08-02985** under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information as has been availed of during the course of this investigation has duly been acknowledged.

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ABSTRACT

A field experiment was conducted at the Sher-e-Bangla Agricultural University farm, Dhaka, Bangladesh from December 2013 to April 2014 to evaluate the effect of phosphorus (viz., 0, 100, 175 and 250 kg TSP ha^{-1}) and potassium (i.e., 0, 60, 120 and 180 kg MoP ha^{-1}) fertilization rate and their combination on the growth and yield of soybean. Individual application of different levels of phosphorus and potassium fertilization showed significant effect on growth, yield and yield attributes studied. Leaf area index, numbers of nodule $plant^{-1}$, numbers of filled pod $plant^{-1}$, numbers of seed pod^{-1}, 1000-seed weight, seed yield, biological yield and harvest index increased significantly up to 175 kg TSP ha^{-1} among phosphorus fertilization. The highest (3.01 t ha^{-1}) seed yield was found from 175 kg TSP ha^{-1} application while the lowest (2.06 t ha^{-1}) from 0 kg TSP ha^{-1} treatment. On the other hand, plant height, numbers of branch $plant^{-1}$, leaf area index, numbers of nodule $plant^{-1}$, fresh weight, dry weight, numbers of filled pod $plant^{-1}$, length of pod, numbers of seed pod^{-1}, 1000-seed weight, seed yield, stover yield and biological yield enhanced significantly up to 120 kg MoP ha^{-1} among potassium fertilization. The highest (3.16 t ha^{-1}) seed yield was found from 120 kg MoP ha^{-1} application while the lowest (2.11 t ha^{-1}) from 0 kg MoP ha^{-1} treatment. The combined application of phosphorus @ 175 kg TSP ha^{-1} and potassium @ 120 kg MoP ha^{-1} gave rise to the highest fresh weight (210.2 g), numbers of filled pod $plant^{-1}$ (63.00), length of pod (3.16 cm), numbers of seed pod^{-1} (3.11), and in turn produced highest (3.67 t ha^{-1}) seed yield. Thus, the combined application of 175 kg TSP ha^{-1} and 120 kg MoP ha^{-1} may be considered to be optimum for getting higher yield of soybean.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEZ	Agro-Ecological Zone
Agric.	Agriculture
Agril.	Agricultural
Agron.	Agronomy
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
Cm	Centi-meter
CV	Coefficient of variance
cv.	Cultivar
DAFF	Department of Agriculture, Forestry and Fisheries
DAS	Days after sowing
Df	Degrees of freedom
DMRT	Duncan's Multiple Range Test
etc.	Electra
FAO	Food and Agriculture Organization
G	Gram (s)
HI	Harvest index
i.e.	That is
IFDC	International Fertilizer Development Centre
J.	Journal
Kg	Kilogram (s)
MS	Master of Science
m^2	Meter squares
Pod^{-1}	Per pod
Res.	Research
SAU	Sher-e-Bangla Agricultural University
Sci.	Science
SE	Standard Error
SRDI	Soil Resource Development Institute
SAIC	SAARC Agricultural Information Centre
$t\ ha^{-1}$	Ton per hectare
viz.	Namely
%	Percentage
@	At the rate of
^{0}C	Degree centigrade

Chapter 1

Introduction

INTRODUCTION

Soybean (*Glycine max L.* Merril) ranks first as an oilseed crop of the world. It has a tremendous value in agriculture as a good source of high quality plant protein and vegetable oils in one hand and nitrogen fixing ability on the other. It belongs to the family Leguminosae, sub family Faboideae. It is classified more as an oil seed crop than as a pulse (Devi *et al.,* 2012). Soybean is quite wide spread in different regions of the world and grows well from the tropics to the temperate zones with greater production in the United States, Brazil, China, Mexico, Indonesia and Argentina. The world production of soybean as estimated in 2008 was 231.27 million ton from an area of 96.47 million hectares (FAO, 2009). It is the most important grain legume of the world and a new prospective crop for Bangladesh (Rahman *et al.,* 2011). On an average Bangladeshi diet only of 8-10 percent of the protein intake originate from animal sources; the rest can be met from plant sources by increasing the consumption of soybean and pulses (Morshed *et al.*, 2008). The protein and oil content together account for about 60% of dry soybean by weight: protein at 40% and oil at 20% (Sodangi *et al.,* 2006). Malik *et al.* (2006) and Dugje *et al.* (2009) depicted that soybean oil is consisted of 85% cholesterol free unsaturated fatty acids. For its nutritive value soybean has been called miracle golden bean, the golden nugget, the nugget of nutrition etc. soybean being a good source of protein, unsaturated fatty acids, minerals like Ca and P and vitamin A, B, C and D can meet up different nutritional needs of human being. Soybean can be used in various ways. It can be used as a pulse crop, can also be used for making nutritious food items like soya dal, soya khechuri, soya pollao, soya bori, soya biscuits, soya bread etc. (Mondal and Wahhab, 2001; Khaleque, 1985).

Soybean oil is very popular as cooking oil but our country is fully depending on import. The production of soybean is very negligible (around only 3000 MT. per year) compared to its lodge demand (Ahmed *et al.,* 2010). Bangladesh has to import soybean cooking oil with US$ 180 million and soybean meal about US$ 25.51 million per year (Khan *et al.*, 2003). Nowadays soybean production area is increasing day by day and in the year 2013 it reaches above 61000 ha (Chowdhury *et al.* 2014). The world average yield of soybean is about 3 t ha^{-1} while that in Bangladesh 1.2 t ha^{-1} (SAIC, 2007). This is mainly due to use of low yield potential varieties and poor agronomic management practices. As a result, the average yield does not appear to be satisfactory. However, there is a scope for improvement of this yield through judicious application of chemical fertilizers and biofertilizers and Bangladesh could meet 40 percent of its soybean oil demand by producing soybean locally, as there is a bright prospect for its farming (Anonymous, 2009).

Phosphorus can play an important role in seed yield as it is one of the limiting plant nutrients for production of soybean (Rao *et al.*, 1995). The most obvious effect of phosphorus is on the plant root system. It promotes early root formation and thus formation of lateral fibrous and healthy roots, which is very important for nodule formation and fixing atmospheric nitrogen. Phosphorus application significantly increases dry matter production as well as yield and yield contributing characters of soybean. It influences the growth of roots, helps uptake of more nutrients and nodule formation, balances the nitrogen deficiency in soil and assists in seed maturation (Manitoba Soil Fertility Guide, 2004). Phosphorus has beneficial effects on both nodulation and nitrogen fixation capacity of soybean. Phosphorus deficiency is reported to reduce nodule formation and growth while an adequate supply leads to good development of nodules (Wall *et al*., 2000). However, very high soil phosphate values may depress seed protein and oil content while yield will be low if available phosphorus is less than 30 kg P ha^{-1} (DAFF, 2010). Murata (2003) reported that low application rates are a limiting factor in soybean growth.

Potassium is known to influence the various physiological and biochemical processes in plants. The relatively large amounts of K are required for high yielding soybean. Soybean has been found to respond to K application at varying rates under different agro-situations (Silva and Bohnen, 1991; Kundu *et al*., 1990; Jones *et al*., 1977). Soybean takes up and accumulates K throughout the growing season (Hanway and Weber, 1971). Potassium deficiency is reported to cause stunted growth and chlorosis (George and Michael, 2002). Tiwani *et al*. (2001) reported K as an important macro-nutrient for metabolic, growth and stress adaptation. Therefore the overall functioning of the plant parts depends on mobility of K as it is responsible for sustaining the movement of other ions like H^+ , sugars and nitrates throughout the whole plant (Marschner, 1995). Potassium deficiency in the soil is not as common as compared to that of phosphorus (Fageria *et al*., 2001). Most of deficiencies are seen in the late stages of soybean growth (Flowering to seed filling stages) since its concentration decreases at crop maturity (Aulakh *et al*., 2002). Thus, deficiency of K at any time during the growing season of soybean may reduce its yields. Applied K increased the number of nodules, total and individual weight of nodules, and the number of pods plant^{-1}.

These results indicate that soybean response to phosphorus and potassium fertilization varies greatly among environments and the plant-soil-climate interactions are not well understood. Also, published information related to effects of phosphorus and potassium on seed quality of soybeans is in Bangladesh. So, further investigation is needed to assess changes in seed growth, yield and quality due to high levels of phosphorus and potassium fertilization in many of today's production environments. Therefore, the present study has been conducted with the following objectives

1. To find out optimum phosphorus level required for growth and yield of soybean
2. To identify the effective potassium level required for soybean cultivation
3. To assess the best combination of phosphorous and potassium fertilization level for optimum growth and yield of soybean

Chapter 2
Review of literature

REVIEW OF LITERATURE

Soybean is an important grain legume crop in the world. It is quite wide spread in different regions of the world and seems to grow well from the tropical and subtropical regions. Researches on the P and K fertilization rate have been carried out by a large number of researchers throughout the world. In Bangladesh, researches on the P and K fertilization rate of soybean are not adequate. However, some important findings have been reviewed in this chapter under the following headings.

2.1. Effect of P fertilizer application on growth and yield of soybean

2.1.1. Plant height

Begum *et al.* (2015) conducted an experiment to study the effects of nitrogen and phosphorus on the performance of soybean. They found that phosphorus showed significant effect on plant height. The results revealed that the highest plant height was found at 54 kg P ha^{-1} and the lowest plant height was observed from 0 kg P ha^{-1}.

Devi *et al*. (2012) conducted a field experiment during rainy seasons of 2007-2009 in India (Manipur) to study the effect of different sources and levels of phosphorus on productivity of soybean [*Glycine max* (L.) Merrill]. The treatments were consisted of four levels of phosphorus (20, 40, 60 and 80 kg P_2O_5 ha^{-1}). They found that plant height was significantly increased by increasing level of phosphorus and application of 80 kg P_2O_5 ha^{-1} produced tallest plant height (47.75 cm) whereas, the shortest was recorded from control.

Malik *et al*. (2006) conducted an experiment to growth and yield response of soybean to seed inoculation and varying phosphorus level. They found that the longest plant height (56.2 cm) was in the treatment of inoculation+120kg P_2O_5 ha^{-1} and in every case shortest result was found where zero P was applied.

Prabhakaran and Lourduraj (2003) reported a field experiments during summer (February-May) and southeast monsoon (June-September) seasons of 1996 to 1997 to study the growth and yield responses of soybean. They found that application of phosphorus significantly increased the plant height.

In an experiment (Singh *et al.* 2001) studied the effect of 0, 30, 60 or 90 kg P_2O_5 ha^{-1} on the growth and development of soybean. They found that the plant height was significantly increased with the higher rate of phosphorus of the study.

Bothe *et al.* (2000) studied the effect of phosphorous fertilizer (0, 25, 50 and 75 kg P_2O_5 ha^{-1}) and observed that phosphorous at the rate of 75 kg ha^{-1} gave the highest values of plant height. Ramasamy *et al.* (2000) reported that P rate i.e. 40, 60 and 80 kg P_2O_5 ha^{-1}, significantly influenced on plant height. The tallest plant height was observed at 80 kg P_2O_5 ha^{-1}.

2.1.2. Number of branches plant^{-1}

Begum *et al.* (2015) was conducted an experiment to study the effects of nitrogen and phosphorus on the performance of soybean. Four levels of phosphorus (0, 18, 36 and 54 kg P ha^{-1}) were considered as treatment for the experiment. They found that phosphorus showed significant effect on number of branches plant^{-1}. They also found that maximum number of branches plant^{-1} (3.37) was obtained from 54 kg P ha^{-1} whereas, minimum obtained from control treatment.

Akter *et al*. (2013) conducted a field experiment to evaluate the effect of P (viz. 0, 15, 30, 50 kg P_2O_5 ha^{-1}) on the growth and yield of soybean. They found that number of branches plant^{-1} increased significantly up to application 50 kg P $ha^{-1.}$

Zafreen (2007) conducted an experiment to study the responses of soybean varieties to different doses of fertilizers. She found that number of branches plant^{-1} was significant due to different doses of P fertilizer application. The maximum number of branches plant^{-1} (4.44) was found with fertilization by double of recommended dose and the lowest (2.61) was obtained in control treatment.

Ramasamy *et al.* (2000) reported that P rate i.e., 40, 60 and 80 kg P_2O_5 ha^{-1}, significantly increased the number of branches plant $^{-1}$. They were found that maximum number of branches plant^{-1} was observed at 80 kg P_2O_5 ha^{-1}.

2.1.3. Leaf area index

Jaidee *et al.* (2013) conducted an experiment to investigate the response of three soybean cultivars to different phosphorus application rate. They used three levels of phosphorus (0, 29 and 58 kg P_2O_5 ha^{-1}) and found that phosphorus application increased the leaf area index of soybean.

Tairo and Ndakidemi (2013) conducted a field experiment to study the effect of *B. japonicum* inoculation and phosphorus supplimentation on growth and leaf chlorophyll content in soybean. They used four levels of phosphorus (0, 20, 40 and 80 kg P ha^{-1}) and found that phosphorus supplimentation significantly increased leaf area index of soybean.

Malik *et al.* (2006) conducted an experiment to growth and yield response of soybean to seed inoculation and varying phosphorus level. They observed that the maximum leaf area index (5.95) was in the treatment of inoculation+120kg P_2O_5 ha^{-1} and in every case lowest result was found where zero P was applied.

2.1.4. Number of nodules plant^{-1}

Devi *et al.* (2012) conducted a field study during rainy seasons of 2007-2009 in India (Manipur) to study the effect of different sources and levels of phosphorus on productivity of soybean [*Glycine max* (L.) Merrill]. The treatments were consisted of four levels of phosphorus (20, 40, 60 and 80 kg P_2O_5 ha^{-1}). They revealed that number of nodules plant^{-1} was significantly increased by increasing level of phosphorus and application of 80 kg P_2O_5 ha^{-1} produced maximum number of nodules (35.67) whereas, the minimum was observed from control.

Jabbar and Saud (2012) conducted an experiment to study the effect of phosphorus application and bacterial inoculation on the growth and yield of soybean. The treatments were consisted of 0, 40, 80 and 120 kg P ha^{-1} and they found that number of nodules increased up to 120 kg P ha^{-1}.

Rotaru (2010) conducted an experiment to know the effect of phosphorus application on soybean and confirmed that the nodulation process respond significantly to supplementary P nutrition. He found that the maximum (41) number of nodules was recorded with 10 kg P ha^{-1} which was higher than of control (37) as well as the rest of the P treatments.

Islam *et al.* (2004) conducted an experiment with 60, 72 and 84 kg P_2O_5 ha^{-1} in soybean (PB-1) and reported that 84 kg P_2O_5 ha^{-1} gave the highest nodule number $plant^{-1}$.

Karim *et al.* (2004) conducted an experiment at Mymensingh, Bangladesh, from 26 august to 30 November 2001 with three levels of phosphorous i.e. 60, 72 and 84 kg P_2O_5 ha^{-1} and observed that the seed yield and seed $plant^{-1}$ of variety shohag increased with higher level of phosphorus. They also observed that shohag @ 84 kg P_2O_5 ha^{-1} gave the highest yield in kharif II-season.

Taiwo *et al.* (1999) observed that phosphorous fertilizer increased in nodulation in both the soybean cultivar (TGX 1740-2F and TGX 1448-2F).

Sa and Israel (1991) stated that the requirements of host plants for optimal growth and symbiotic dinitrogen fixation processes for P have been assessed by determination of nodule development and functioning.

Singh and Bajpai (1990) in a trial of 0-100 kg P_2O_5 ha^{-1} observed that 80 kg P_2O_5 ha^{-1} gave highest seed yield of 2.04 t ha^{-1} compared with 1.45 t ha^{-1} without phosphorous.

2.1.5. Dry weight plant^{-1}

Begum *et al.* (2015) also reported that that highest dry weight plant $^{-1}$ obtained from 54 kg P ha^{-1} whereas, the lowest dry weight plant^{-1} was observed from 0 kg P ha^{-1}.

Jabbar and Saud (2012) reported that dry weight of soybean varied significantly and increased when phosphorus used at the rate of 120 kg ha^{-1}.

Bothe *et al.* (2000) studied the effect of phosphorous fertilizer (0, 25, 50 and 75 kg P_2O_5 ha^{-1}) and observed that phosphorous at the rate of 75 kg P_2O_5 ha^{-1} gave the highest values for dry matter plant^{-1} (57.46 g). On the other hand Vieira *et al.* (1980) reported that application of phosphorous increased plant weight but effect was not significant between the different phosphorus rates.

2.1.6. Number of pods plant^{-1}

Begum *et al.* (2015) found that phosphorus showed significant effect on number of filled pods plant^{-1}. The number of filled pods plant^{-1} (54.49) was the highest in 54 kg P ha^{-1} and the lowest number of filled pods plant^{-1} was observed from 0 kg P ha^{-1}.

Ali *et al.* (2013) carried out an experiment at the agronomy field laboratory, Bangladesh Agricultural University, Mymensingh during January to April 2012 to find out the effect of P on yield performance of soybean. They used four levels of P viz. 0, 40, 80 and 120 kg P_2O_5 ha^{-1}. They found that the application of 80 kg P_2O_5 ha^{-1} produced the highest number of filled pods plant^{-1} (50.43) and the lowest (40.10) reported from 120 kg P_2O_5 ha^{-1}. Similarly, Jaidee *et al.* (2013) reported that 58 kg P_2O_5 ha^{-1} application rate increased the number of filled pods plant^{-1} of soybean.

Devi *et al.* (2012) revealed that number of pods plant^{-1} was significantly varied with phosphorus and application of 80 kg P_2O_5 ha^{-1} produced maximum (76.25) number of pods whereas, the lowest was observed from control.

Morshed *et al*. (2008) conducted a field experiment to find out the effect of phosphorus on the growth and yield of soybean. They found that number of pods plant^{-1} increased with the increase of P levels up to 11.25 kg P ha^{-1}.

Malik *et al*. (2006) stated that highest number of pods plant^{-1} (36.53) was from the treatment inoculation+120kg P_2O_5 ha^{-1} and in every case lowest result was found where zero P was applied.

Manga *et al.* (2004) reported that the growth and yield of soybean were influenced by phosphorus and molybdenum fertilization. In their trail, the crop received 0, 13 or 26 kg P and 0, 0.5 or 1.0 kg ammonium molybdate ha^{-1}. They found that phosphorus application significantly increased the number of pods plant^{-1}.

Kohli *et al.* (2002) conducted an experiment and studied the effect of different levels of P and K fertilizer on the response of soybean. Three levels of P (0, 13 and 26 kg ha^{-1}) and two levels of K (0 and 33 kg ha^{-1}) were applied. P significantly increased number of pods plant^{-1}.

Mohan and Rao (1997) observed that number of pods plant^{-1}of soybean generally increased with increasing rate of 90 kg P_2O_5 ha^{-1}. In a trial with 0, 30, 60, or 90 kg P_2O_5 ha^{-1} on a clay loam soil, the yield of soybean was found increase only with 30 kg P_2O_5 ha^{-1} but the higher phosphorus did not give further significant increase (Tomar *et al.,* 1991). Applied phosphorus from 26 to 51 kg ha^{-1} increased pod number plant^{-1}.

Syafruddin *et al.* (1990) observed that application of phosphorous increased number of pods plant^{-1} and decreased the percentage of empty pods in soybean cv.Orba.

Reddy and Giri (1989) reported that phosphorus application @ 120 kg P ha^{-1} increased the pod yield of soybean.

Haque *et al.* (1978) found that increased doses of phosphorus increased the number of pods plant^{-1}.

2.1.7. Length of pod

Farnia and Gudiny (2014) conducted a field experiment to investigate the effect of a some N and P biofertilizars and symbiotic nitrogen fixing bacterium *Bradyrhizobium japonicum* on growth, yield and yield components of soybean (*Glycine max* (L.) Williams) and found that P biofertilizers had a positive effect on pod length. In all combined treatment pods had a high (4.2-4.6 cm) length rather than control treatment. Non application of each N and P biofertilizers had a lowest (3.8 cm) pod length and difference of it with other treatment was significant.

Piraveena and Seran (2013) carried out an experiment in the Eastern region of Sri Lanka to evaluate the effect of cattle manure with different levels of rock phosphate application on seed yield of soybean (*Glycine max*) in sandy regosol and reported that pod length ranged from 3.39 to 3.44 cm and higher value was obtained in the combined application of cattle manure with rock phosphate.

2.1.8. Number of seeds pod^{-1}

Ali *et al.* (2013) also found that the application of 80 kg P_2O_5 ha^{-1} produced the maximum number of seeds pod^{-1} (2.93) and the minimum (2.81) reported from 120 kg P_2O_5 ha^{-1}.

Devi *et al*. (2012) also observed that number of seeds pod^{-1} was significantly varied with phosphorus and application of 80 kg P_2O_5 ha^{-1} produced maximum number of seeds (2.84) whereas, the minimum was observed from control.

Morshed *et al*. (2008) conducted a field experiment to find out the effect of phosphorus on the growth and yield of soybean. They found that number of seeds pod^{-1} increased with the increase of P levels up to 11.25 kg P ha^{-1}.

Malik *et al*. (2006) also found that maximum number of seeds pod^{-1} (2.73) was in the treatment of inoculation+120kg P_2O_5 ha^{-1} and in every case minimum result was found where zero P was applied.

Tomar *et al.* (2004) in an experiment in Madhya Pradesh, India, during kharif season observed that the number of seeds pod^{-1} increased with the increase of phosphorous application.

Kausandiker *et al.* (2003) reported that application of P_2O_5 at 90 kg P_2O_5 ha^{-1} gave the highest number of pods plant^{-1}, 1000-seed weight, seed yield and stover yield.

2.1.9. 1000-seed weight

Begum *et al.* (2015) reported that the highest 1000-seed weight (122.2g) was observed in 54 kg P ha^{-1} whereas, lowest from control (0 kg P ha^{-1}) treatment.

Ali *et al.* (2013) also observed that the application of 80 kg P_2O_5 ha^{-1} produced the maximum 1000-seed weight (106.6g) and the minimum (100.6g) reported from 120 kg P_2O_5 ha^{-1}.

Devi *et al*. (2012) found that number of 1000-seed was significantly varied with phosphorus and application of 80 kg P_2O_5 ha^{-1} produced highest weight of 1000 seeds (134.3g) while, the lowest was observed from control treatment.

Hanumanthappa *et al.* (1998) carried out an experiment to know the effect of different levels of phosphorous on yield and yield components of soybean varieties. They found that 1000-seed weight varied with phosphorous levels.

In a trial with 0, 30, 60, 0r 90 kg P_2O_5 ha^{-1} on a clay loam soil, the yield of soybean was found to increase only with 30 kg P_2O_5 ha^{-1} but the higher phosphorous did not give further significant increased in yield (Tomar *et al.* 1991).

2.1.10. Seed yield

Begum *et al.* (2015) observed that seed yield varied significantly due to phosphorus application. The results revealed that the highest seed yield (2.09 t ha^{-1}) obtained from 54 kg P ha^{-1} whereas, the lowest (1.30 t ha^{-1}) obtained from control treatment.

Jaidee *et al*. (2013) observed that P fertilizer had significant effect on seed yield of soybean and phosphorus application at the rate of 58 kg P_2O_5 ha^{-1} gave the highest seed yield of soybean.

Devi *et al*. (2012) reported that number of seed yield was significantly varied with phosphorus and application of 80 kg P_2O_5 ha^{-1} produced maximum seed yield (1656 kg ha^{-1}) while, the lowest was observed from control treatment.

Fatima *et al*. (2007) conducted a pot experiment with or without phosphorus on soybean growth, yield and nitrogen fixation parameters. They found that seed yield was increased by applying by *Rhizobium* mixed culture with phosphorus.

Malik *et al*. (2006) also found that seed yield gradually increased with the combination of inoculation and P fertilizer application where maximum seed yield obtained was 1955.56 kg ha^{-1} at 120 kg P ha^{-1} and the minimum was 1274.07 kg ha^{-1} for the control.

Islam *et al.* (2004) in an experiment with 60, 72 and 84 kg P_2O_5 ha^{-1} in soybean cv. PB-1 observed that seed yield increased with the increase of phosphorous application.

Shah *et al*. (2001) conducted an experiment with 0, 40, 60, and 80 kg P_2O_5 ha^{-1} observed that phosphorus uptake efficiency and yield of soybean were increased with the increases of phosphorus application.

Navale *et al.* (2000) in an experiment in Maharastra, India, during the kharif season observed that seed yield significantly increased up to 120 kg P_2O_5 ha^{-1}. Osman *et al.* (2000) found the highest seed yield of soybean with 60 kg P_2O_5 ha^{-1} out of 20, 40, and 60 kg P_2O_5 ha^{-1}.

Raychaudhuri *et al.* (1997) stated that inoculation with *Rhyzobium* and phosphorous (60 kg P_2O_5 ha^{-1}) significantly increased seed yield of soybean. Uppal *et al.* (1997) reported that highest seed yield was obtained with up to 80 kg P_2O_5 ha^{-1} when applied at 30% available soil moisture depletion (ASMD).

Narayana *et al. (*1995) reported that soybean seed yield was increased with the increased rate of phosphorus application from 0 to 50 kg P_2O_5 ha^{-1}. Surendra *et al*. (1995) reported that soybean cv. PK-262 gave seed yield of 2.46 t ha^{-1} at without phosphorus application but the highest yield was 3.34 t ha^{-1} obtained with 80 kg P_2O_5 ha^{-1}.

Syafruddin *et al.* (1990) observed that application of phosphorous increased seed yield in soybean cv. Orba. Seed yield was 0.75, 0.81 and 1.19 t ha^{-1} with 0, 45, 90 kg ha^{-1} respectively, without added $ZnSO_4$. Singh and Bajpai (1990) in a trial of 0-100 kg P_2O_5 ha^{-1} observed that 80 kg P_2O_5 ha^{-1} gave highest seed yield of 2.04 t ha^{-1} compared with 1.45 t ha^{-1} without phosphorus.

Kalia *et al.* (1986) observed that 100 kg P_2O_5 ha^{-1} increased the seed yield significantly compared to other doses through favorable effect of yield attributes.

Krisnamoorthy *et al.* (1981) used 0, 40, 80 and 120 kg P_2O_5 ha^{-1} and obtained the highest seed yield of 1.77 and 2.02 t ha^{-1} in summer and monsoon season, respectively, by applying 120 kg P_2O_5 ha^{-1}.

Cassman *et al.* (1980) conducted an experiment and they found that maximum yield of soybean in Haiku clay when the field had been fertilized with 120 kg P ha^{-1}.

2.1.11. Stover yield

Begum *et al.* (2015) observed that stover yield varied significantly due to phosphorus application and highest stover yield obtained from 54 kg P ha^{-1} whereas, the lowest obtained from control treatment.

Akter *et al*. (2013) found that stover yield increased significantly up to application 50 kg P $ha^{-1.}$ Ali *et al.* (2013) also found P had non-significant effect on stover yield of soybean. The highest stover yield was reported from 80 kg P_2O_5 ha^{-1} whereas; the minimum was obtained from 120 kg P_2O_5 ha^{-1}.

Devi *et al*. (2012) reported that stover yield significantly varied with phosphorus and the maximum stover yield was obtained from 80 kg P_2O_5 ha^{-1} followed by 60 kg P_2O_5 ha^{-1} while, the lowest was observed from control treatment.

Islam *et al*. (2004) observed that stover yield increased with the increase of phosphorus application. Tomar *et al*. (2004) also observed that stover yield increased with the increase of phosphorous application.

Kausandiker *et al*. (2003) reported that application of phosphorus at 90 kg P_2O_5 ha^{-1} gave the highest stover yield.

Aulakh *et al*. (2002) conducted an experiment with different levels of phosphorus applied to soybean (0, 40, 60, 80 and 100 kg ha^{-1}) and found that an increased yield over no P being applied (control) up to 80 kg ha^{-1}. Higher application of P fertilizer (> 80 kg ha^{-1}) seemed to have reduced yield.

2.1.12. Biological yield

Malik *et al*. (2006) also observed that the highest biological yield (4785.19 kg ha^{-1}) was from inoculation+120kg P_2O_5 ha^{-1} and in every cases lowest result was found where zero K was applied.

Naik *et al*. (1991) conducted an experiment with P utilization in soybean influenced by time of sampling. In field trials in the rabi seasons 1987-1989 on sandy loam soil the effects of 0, 40, 80, 120 kg P_2O_5 ha^{-1} on biological yield and P uptake of soybeans were studied at flowering and maturity. P application increased biological yield, although increase was significant only at maturity in 1987-88.

2.1.13. Harvest index

Sharma *et al.* (2011) conducted an experiment. They used four varieties of soybean which were tested under different regimes of applied phosphorus. They reported that application of phosphorus significantly increased the harvest index up to 60 kg P ha^{-1}.

Mabapa *et al*. (2010) conducted an experiment to effect of P fertilizer rates on growth and yield of soybean. The experiments consisted of a factorial combination of fertilizer rates (0, 30 and 60 kg P ha^{-1}). They found that P did not affect Harvest index.

Malik *et al*. (2006) found that the maximum (40.85%) harvest index (HI) was from inoculation+120kg P_2O_5 ha^{-1} and in every case lowest result was found where zero K was applied.

2.2. Effect of K fertilizer application on growth and yield of soybean

2.2.1. Plant height

Mokoena (2013) studied the effect of potassium fertilizer (0, 50 and 100 kg K ha^{-1}) on soybean and observed that soybean plant height was only significantly impacted by the effect of K. Plant height was significantly increased by applying K (50 or 100 kg ha^{-1}), as compared to where zero K was applied.

2.2.2. Leaf area index

Kolar and Grewal (1994) conducted an experiment to study the potassium nutrition of soybean. They found that leaf area index of soybean responded significantly up to 50 kg K ha^{-1}.

2.2.3. Number of pods plant^{-1}

Xiang *et al.* (2012) stated that the maximum (81.6) pods plant^{-1} of soybean was produced by when K was used at the rate of 112.5 kg ha^{-1} and the minimum (72.1) pods plant^{-1} (72.1) was found when no potassium was applied.

2.2.4. Number of seeds pod^{-1}

Azizi and Sorouri (2014) conducted an experiment to evaluate the effect of potassium, zinc and manganese on agronomic traits of soybean and they used potassium in three levels (0, 80 and 160 kg ha^{-1}). They observed that maximum number of seeds pod^{-1} was obtained from 160 kg ha^{-1} K_2O + Solopotash.

Xiang *et al.* (2012) conducted an experiment and they were observed that the highest (1.28) seeds pod^{-1} was produced by relay strip intercropping soybean at the rate of 112.5 kg K ha^{-1} whereas, the lowest was recorded in the zero-K control.

2.2.5. 1000-seed weight

Mokoena (2013) stated that effect of K significantly influenced 1000-seed mass. The application of 100 kg K ha^{-1} resulted in a 1000-seed mass of 143.3 g and the lowest obtained from where zero K was applied.

Khan *et al*. (2004) conducted an experiment to assess the influence of different levels of potassium fertilization (0, 25, 50, 75, 100, 125 and 150 kg ha^{-1}) on growth, seed yield and oil contents of soybean. They revealed that K fertilizers had a significant influence on 1000-seed weight. The highest values of 1000-seed weight were recorded in when potassium was applied @ 150 kg ha^{-1} and the lowest value of was noted in control treatment.

2.2.6. Seed yield

Nelson *et al.* (2012) conducted an experiment to know the effect of potassium on glyphosate resistant soybean response and weed control. The treatments were consisted of 2.2, 8.8 and 17.6 kg K ha^{-1}. They found that seed yield increased with fertilizer additives at 8.8 kg K ha^{-1}.

Xiang *et al.* (2012) also observed that the highest seed yield (2695 kg ha^{-1}) was produced by relay strip intercropping soybean at the rate of 112.5 kg ha^{-l} and the lowest seed yield was recorded in the zero-K control.

Camargo *et al.* (2012) conducted an experiment to evaluate the effects of P and K on yield and quality of soybean. The treatments were consisted of 0, 26, 35 and 53 kg ha^{-1} of P and o, 33, 50 and 66 kg ha^{-1} of K. They found that maximum soybean yield was obtained with 30.3 to 36 kg ha^{-1} of K.

Pettigrew (2008) conducted an experiment to know the effect of potassium on seed yield and quality production for maize, wheat, soybean and cotton. He reported that potassium deficiency reduced both the number of leaves and the size of leaf area. So, the photosynthetic rate also reduced and ultimately seed yield was hampered. He also found that potassium significantly increased the seed yield of soybean.

2.2.7. Harvest index

Xiang *et al.* (2012) stated observed that the highest harvest index (42.8%) was produced by relay strip intercropping soybean at the rate of 112.5 kg K ha^{-1} and the lowest (40.0%) was recorded in the zero-K control.

2.3. Combined effect of P and K fertilizer application on growth and yield of soybean

Mokoena (2013) studied the effect of potassium fertilizer (0, 50 and 100 kg K ha^{-1}) and phosphorus fertilizer (0, 20 and 40 kg P_2O_5 ha^{-1}) and observed that P x K interactions had non-significant effect on the number of nodules, 1000-seed weight and seed yield of soybean. He also found that the plants where P and K fertilizers were applied were significant impacted of the number of pods. P fertilizer alone at 10 kg P ha^{-1} had a much higher significant impacted on pod number than either K alone or any of the P x K combinations however, too high P levels (>20 kg P ha^{-1}) resulted in reduced pods number $plant^{-1}$. Too high

(>150 kg K ha^{-1}) and too low (<50 kg K ha^{-1}) K application rate also resulted in pods number $plant^{-1}$. He also found that amongst all the treatment combinations (except for 10 x 0 kg P x K ha^{-1}) 10 x100 kg P x K ha^{-1} showed the highest number of pods as compared of treatment combination.

Camargo *et al.* (2012) conducted an experiment to evaluate the effects of P and K on yield and quality of soybean. The treatments were consisted of 0, 26, 35 and 53 kg ha^{-1} of P and o, 33, 50 and 66 kg ha^{-1} of K. They found that highest soybean yield was obtained with 35 kg ha^{-1} P and 30.3 to 36 kg ha^{-1} of K. They also found that at 53 kg ha^{-1} P seed yield was lower than 35 kg ha^{-1} P.

Xiang *et al*. (2012) conducted an experiment to determine the effect of phosphorus (P) application (0, 8.5, 17.0 and 25.5 kg ha^{-1}) and potassium (K) application (0, 37.5, 75.0 and 112.5 kg ha^{-1}) on growth and yield of soybean. They found that both P and K significantly affected the number of branches of soybean, but the interaction was not significant. The branch number $plant^{-1}$ ranged from 5.0 to 6.5 and 4.7 to 6.5 with the P and K application, respectively. The maximum branches number $plant^{-1}$ (6.5) were observed at the level of 17 or 75.0 kg K ha^{-1}, 38.3 or 30.0% higher than zero-P control and zero-K control, respectively. The interaction of P × K indicated that leaf area increased at first and then decreased with increase in P applied with K (75.0 kg ha^{-1}), but there was no obvious regularity in P application treatment with K (0, 37.5, 112.5 kg ha^{-1}). Interaction of P × K indicated that increasing amount of K application from 0 to 112.5 kg ha^{-1} increase pods $plant^{-1}$ and seeds pod^{-1} significantly, similar trend was also observed at the rate of P application from 0 to 17 kg ha^{-1}. The harvest index increased first and then decreased with increment of P application when at the rate of K application (0, 75, 112.5 kg ha^{-1}), while at the level of 37.5 kg K ha^{-1}, the harvest index increased with increasing of P application amount.

Krueger *et al*. (2011) conducted an experiment to investigated influence of P and K fertilization on soybean seed yield and quality. The treatments were consisted of four rates 0, 31, 63 and 123 kg P_2O_5 and 0, 39, 78 and 164 kg K_2O ha^{-1} respectively. They found that both P and K showed significant effect on seed yield of soybean.

From the above reviews on the effect of phosphorus and potassium fertilizers on soybean by different researchers from different locations in home and abroad it is revealed that there exists ample scopes to study on the effect of phosphorus and potassium fertilization on soybean.

Chapter 3

Materials and Methods

MATERIALS AND METHODS

This chapter presents a brief description about experimental period, site description, climatic condition, crop or planting materials, treatments, experimental design and layout, crop growing procedure, fertilizer application, intercultural operations, data collection and statistical analyses.

3.1. Location

The field experiment was conducted at the Agronomy research field, Sher-e-Bangla Agricultural University, Dhaka during the period from December 2013 to April 2014. Geographically the experimental field is located at 23°46' N latitude and 90° 22' E longitude (Google maps, 2014) at an elevation of 8.2 m above the sea level belonging to the Agro-ecological Zone “AEZ-28” of Madhupur Tract (BBS, 2011). The location of the experimental site has been shown in Appendix I.

3.2. Climate

The experimental area is situated in the sub-tropical climatic zone and characterized by heavy rainfall during the months of April to September (Kharif Season) and scanty rainfall during the rest period of the year. The Rabi season (October to March) is characterized by comparatively low temperature and plenty of sunshine from November to February. The weather data during the study period at the experimental site are shown in Appendix II.

3.3. Soil

The soil of the research field is slightly acidic in reaction with low organic matter content. The selected plot was above flood level and sufficient sunshine was available having available irrigation and drainage system during the experimental period. Soil samples from 0-15 cm depths were collected from experimental field. The analyses were done from Soil Resources Development Institute (SRDI), Dhaka. The experimental plot was also high land, having p^H

5.8. The physicochemical property and nutrient status of soil of the experimental plots are given in Appendix III.

3.4. Plant materials and features

The variety of soybean used in this experiment was BARI Soybean-6. The seed of this variety was collected from Bangladesh Agricultural Research Institute, Joydebpur, Gazipur. This released variety has excellent seed quality and superior to others. Its field duration is about 100-110 days. Its height is about 50-55 cm. BARI Soybean-6 contains 20-21% oil and 42-44% protein. Seed yield is about 1.80-2.10 t ha^{-1} (BARI, 2011).

3.5. Experimental treatments

The experiment consisted of two treatment factors as mentioned below:

Factor A: Phosphorous fertilization; level- 4

P_0 = No TSP
P_1= 100 kg TSP ha^{-1}
P_2= 175 kg TSP ha^{-1}
P_3 = 250 kg TSP ha^{-1}

Factor B: Potassium fertilization; level- 4

K_0 = No MoP
K_1 = 60 kg MoP ha^{-1}
K_2 = 120 kg MoP ha^{-1}
K_3 =180 kg MoP ha^{-1}

3.6. Design and layout

The experiment was laid out in a split plot design with three replications. The size of the individual plot was 2 m x 2 m and total numbers of plots were 48. There were 16 treatment combinations. Each block was divided into 16 unit plots. Phosphorous fertilization treatments along the main plot and potassium fertilization treatments were placed in the sub plot. Layout of the experiment was done on December 27, 2013 with inter plot spacing of 0.50 m and inter block spacing of 0.75m. A layout of the experimental plot is given on Figure 1.

3.7. Land preparation

The land of the experimental field was first opened on December 20, 2013 with a power tiller. Then it was exposed to the sunshine for 7 days prior to the next ploughing. Thereafter, the land was ploughed and cross-ploughed to obtain good tilth. Deep ploughing was done to produce a good tilth, which was necessary to get better yield of the crop. Laddering was done in order to break the soil clods into small pieces followed by each ploughing. All the weeds and stubbles were removed from the experimental field.

3.8. Fertilizer application

The applied doses of urea (60 kg ha^{-1}) and gypsum (115 kg ha^{-1}) as per recommended dose (BARC, 1989) were applied all plots of the experimental field. Triple superphosphate and muriate of potash were considered as sources of P and K. The fertilizers were applied as per treatment. One-third parts of urea and all other fertilizer were applied at the time of final land preparation and another two portion of urea were applied after 20 DAS and 40DAS.

3.9. Seed sowing

Sowing was done on 28 December, 2013. Seeds were sown in 30 cm apart rows and seed to seed distances were maintained at first in 5cm and later in 10 cm to conform the exact plant density. Furrows were made by hand rake and seeds were placed in the furrows by hand and then covered properly with soil.

3.10. Intercultural operations

The following intercultural operations were done for ensuring the normal growth of the crop.

3.10.1. Thinning

At 15 DAS, excess plants were thinned out and maintained plant to plant distance 10cm.

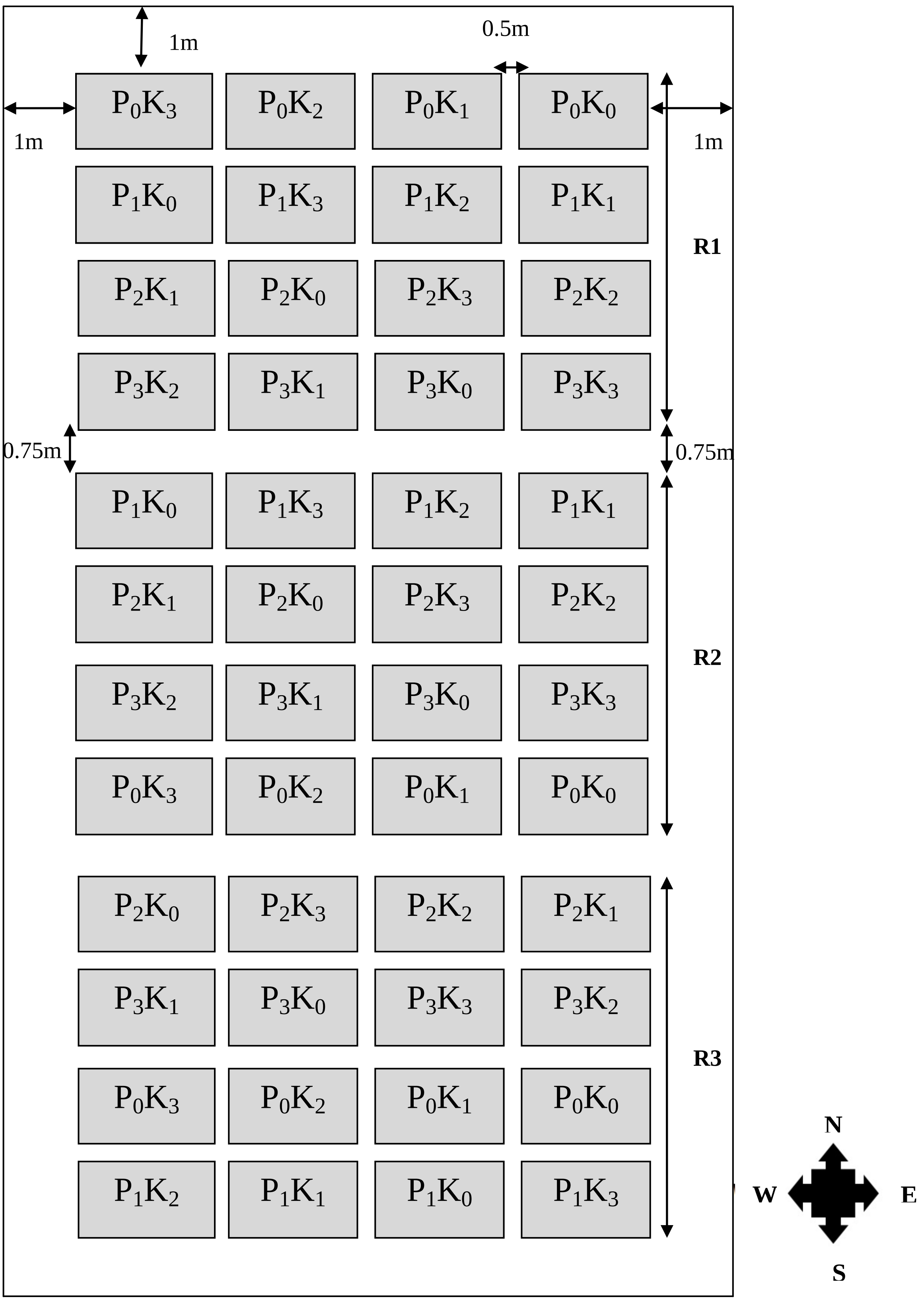


Figure 1. Layout of the experimental field

3.10.2. Weeding

The crop was weeded twice. First weeding was done at 25 days after sowing (DAS) and second weeding was done at 45 DAS. Demarcation boundaries and drainage channels were also kept weed free.

3.10.3. Irrigation

Irrigation was done at 30 DAS after sowing (pre-flowering) stage and then at 60 DAS (pod formation stages) as per recommendation (BARI, 2011). Proper drainage system was also made for draining out excess water.

3.10.4. Plant protections

The soybean plants were infested by cutworms (*Agrotis ipsilon*) at early growth stage which were controlled by applying Darsban 20 EC @ 5ml/L of water. Diseased or off type plants were uprooted as and when required.

3.11. General observations of the experimental field

Regular observations were made to see the growth stages of the crop. In general, the field looked nice with normal green plants which were vigorous and luxuriant in the treatment plots than that of control plots.

3.12. Sampling and harvesting

Maturity of crop was determined when 95 % of the pods become brown in colour. Three sample plants were collected from each plot before harvesting for taking yield attributes data. The plants of central 1 m^2 area were harvested by placing quadrates at random for recording yield data. Harvesting was done on 29 April, 2014. The harvested crops from each plot were tied up into bundles separately, tagged and brought to the clean threshing floor. The same procedure was followed for sample plants.

3.12.1. Threshing

The crop bundles were sun dried for four days by spreading them on the threshing floor. Seeds were separated from the stover by hand machine and rubbing.

3.12.2. Drying

Seeds and stover were cleaned and dried in the sun for four consecutive days. After proper drying of seeds to a moisture content of 12 % were kept in polythene bags. Moisture contents were determined by moisture meter.

3.12.3. Cleaning and weighing

Dried seeds and stover was weighed plot wise. After that the weights were converted into t ha^{-1}.

3.13. Collection of data

Three plants in each plot were selected and tagged. All the growth data (except dry weight) were recorded from those three selected plants.

The following data were collected –

A. Crop growth characters

1. Plant height (cm) at 30, 45, 60, 75, 90 and 105 DAS
2. Number of branches $plant^{-1}$ at 45, 60, 75, 90 DAS, and at harvest
3. Leaf area index at 30, 45, 60, 75, 90 and105 DAS
4. Number of nodules $plant^{-1}$ 30, 60 and 90 DAS
5. Fresh weight (g $plant^{-1}$) at 30, 60 and 90 DAS
6. Dry weight (g $plant^{-1}$) at 30, 60 and 90 DAS

B. Yield contributing characters

1. Number of filled pods $plant^{-1}$
2. Length of pod (cm)
3. Number of seeds pod^{-1}

4. 1000-seed weight (g).

C. Yield and harvest index

1. Seed yield (t ha^{-1})
2. Stover yield (t ha^{-1})
3. Biological yield (t ha^{-1})
4. Harvest index (%)

3.14. Methods of recording data

A. Crop growth parameters

i. Plant height (cm)

The height of soybean plants was recorded at 30, 45, 60, 75, 90 and 105 DAS. The heights of three preselected sample plants were measured from the ground level to the tip of the shoot. Then the data was averaged and expressed in cm.

ii. Number of branches plant^{-1}

Total branch number was taken at 45, 60, 75, 90 DAS and at harvest. All the branches present on three preselected sample plants were counted and averaged them to have number of branches plant^{-1}.

iii. Leaf area index

Leaf area index was taken at 30, 45, 60, 75, 90 and 105 DAS. All the data present on three preselected sample plants were counted and average value of leaf area index was counted.

Leaf area index=Leaf area/Ground area

=Length x breadth x 0.75 x No. of leaves/ Spacing

iv. Number of nodules plant^{-1}

Total nodules number was taken at 30, 60 and 90 DAS. The soils was soaked and three plants were collected randomly from the inner rows of each plot by a khurpi and counted nodule number then averaged them to have number of nodules plant^{-1}.

v. Fresh weight plant^{-1}

The fresh weight of soybean plants was recorded at 30, 60 and 90 DAS. Three plants were collected randomly from the inner rows of each plot. The fresh weight of the samples was taken using a sensitive digital electric balance. The mean weight was calculated and the weight was expressed in g plant^{-1}.

vi. Dry weight plant^{-1}

The dry weight of soybean plants was recorded at 30, 60 and 90 DAS. After fresh weight measured from three randomly selected plants were dried separately for 72 hours in an electric oven set at 60^0C. The dry weight of the samples was taken using a sensitive digital electric balance. The mean weight was calculated and the weight was expressed in g plant^{-1}.

B. Yield contributing characters

i. Number of pods plants^{-1}

All the pods of the preselected three sample plants in each plot were counted and averaged them to have pods plant^{-1}.

ii. Pod length

The lengths of three randomly selected pods taken from sample plants were measured. Mean data was expressed in centimeter (cm).

iii. Number of seeds pod^{-1}

Number of total seeds of three sample plants from each plot was noted and the mean number was expressed pod^{-1} basis.

iv. Weight of 1000-seed (g)

One thousand sun dried cleaned seeds were counted randomly from the seed stock of sample plants. Weight of 1000 seeds were then recorded by means of a digital electrical balance and expressed in gram (g).

C. Yield and harvest index

i. Seed yield

Seeds obtained from harvested (1.0 m^2) area of each unit plot were dried in the sun and weighed. The seed weight was expressed as t ha^{-1} on 12% moisture basis. Grain moisture content was measured by using digital moisture meter.

ii. Stover yield

The stover yields obtained from the harvested 1.0 m^2 area of each unit plot were dried separately and weights were recorded. These weights were converted to t ha^{-1}.

iii. Biological yield

Biological yield was calculated by using the following formula:

Biological yield= Grain yield + stover yield

iv. Harvest index (%)

Harvest index is the relationship between grain yield and biological yield (Gardner *et al.,* 1985). It was calculated by using the following formula:

$$\text{HI (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

3.15. Statistical analysis

The data collected on different parameters were statistically analyzed to obtain the level of significance by using MSTAT-C computer package programme. The significant differences among the treatment means were compared by Duncan's Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

Chapter 4

Results and Discussion

RESULTS AND DISCUSSION

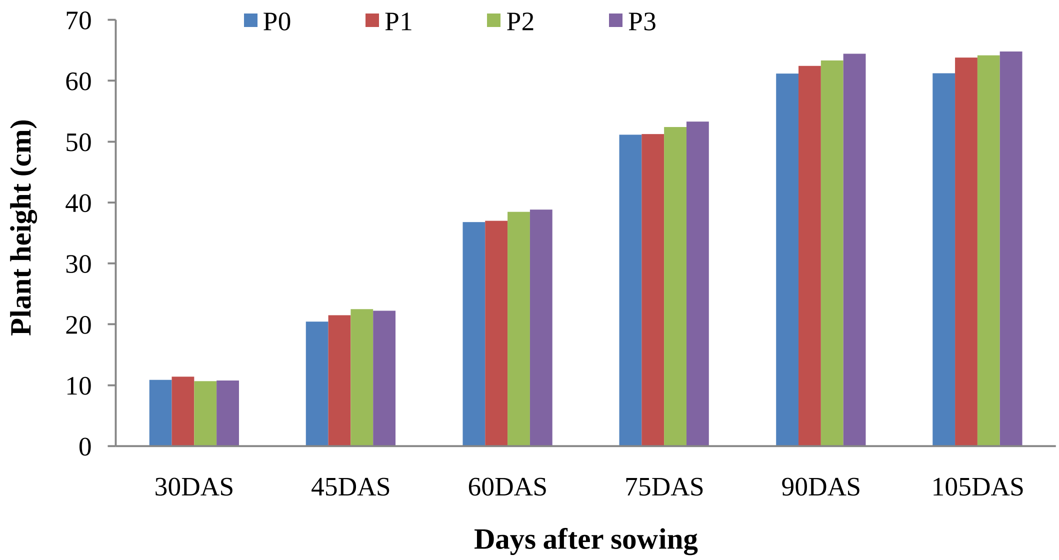
This chapter comprises of presentation and discussion of the results obtained from a study to investigate the effect of phosphorus (P) and potassium (K) fertilization rate on the growth, development and yield of soybean.

4.1. Crop growth characters

4.1.1. Plant height

4.1.1.1. Effect of P fertilizer application

Plant height of soybean was not significant effect with different levels of P application at different days after sowing (DAS) (Figure 2 and Appendix IV). The figure indicated that plant height showed an increasing trend with advancement of time up to 90 DAS and then slightly increased at 105 DAS. Tomar *et al*. (2004) showed that increased levels of P had positive effects on plant height. This finding is also differing to those of Qureshi *et al*. (1986) who found a significant increase in plant height due to P application. Increased plant height due to phosphorus was also reported by Menaria *et al.* (2003).

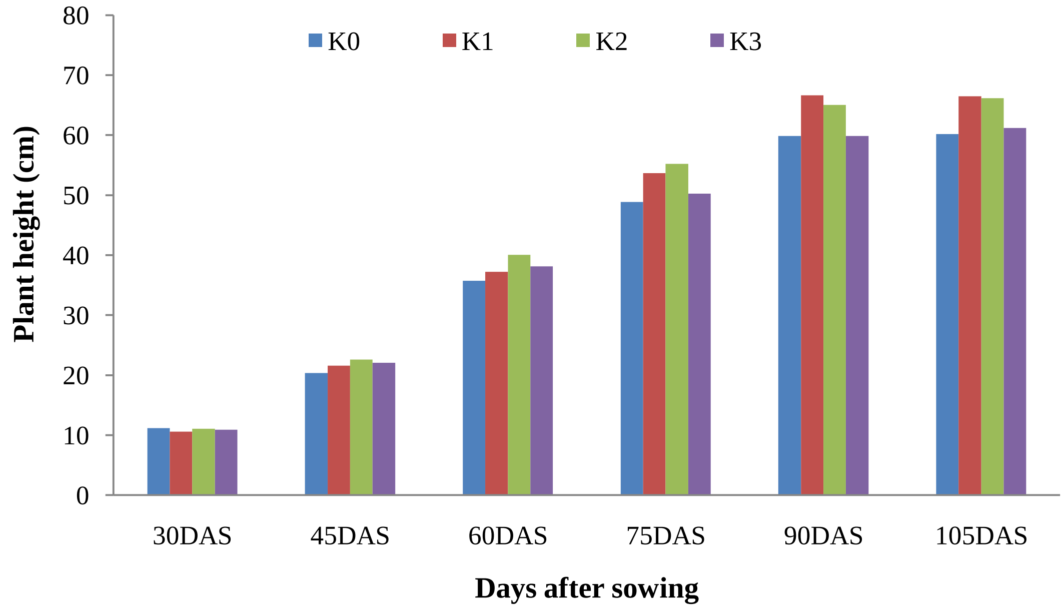


(P_0= No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha$^{-1,}$ P_3=250 kg TSP ha^{-1})

Figure 2. Effect of P fertilization level on plant height of soybean at different DAS (SE = NS, NS, NS, NS, NS and NS at 30, 45, 60, 75, 90 and 105 DAS, respectively)

4.1.1.2. Effect of K fertilizer application

Plant height of soybean was varied significantly due to different levels of K application at different DAS except 30 DAS (Figure 3 and Appendix IV). The figure indicated that plant height showed an increasing trend with advancement of time up to 90 DAS and then slightly increased at 105 DAS. It could be inferred from the figure that, K_2 showed the tallest plant (22.58, 40.03 and 55.24 cm) and K_0 showed the shortest (20.36, 35.73 and 48.86 cm) for sampling dates of 45, 60 and 75 DAS, respectively. This might be due to the reason that high root shoot ratio is associated with potassium uptake. These results are in line with Ali *et al.* (1996) and Hussain (1994).



(K_0= No MoP, K_1=60 kg MoP ha^{-1}, K_2=120 kg MoP ha^{-1}, K_3=180 kg MoP ha^{-1})

Figure 3. Effect of K fertilization level on plant height of soybean at different DAS (SE = NS, 0.66, 1.32, 1.32, 1.63, 1.65 and 1.26 at 30, 45, 60, 75, 90 and 105 DAS, respectively)

4.1.1.3. Combined effect of P and K fertilizer application

Combined effect of different level of P and K application on plant height of soybean was significantly affected at different DAS except 30 and 60 DAS (Table 1). At 45 DAS, the tallest plant (23.75 cm) was observed from P_2K_3 which was statistically at par with P_2K_2 (23.31 cm) while, the shortest (19.11 cm) was obtained from P_0K_0. At 75 DAS, the tallest plant (59.71 cm) was observed from P_3K_2 which was statistically similar with P_1K_1 (54.89 cm) and P_0K_2 (54.78 cm) and the shortest (47.78 cm) was obtained from P_1K_0 which was which was statistically at par with P_3K_0 (48.18 cm). At 90 DAS, the tallest plant (72.79 cm) was obtained from P_3K_1 which was statistically similar with P_2K_2 (68.12 cm) and P_1K_2 (66.44 cm) whereas, the shortest (57.46 cm) observed from P_3K_3 which was statistically at par with P_1K_3 (56.89 cm) and P_0K_0 (59.89 cm). At 105 DAS, the tallest plant was (72.67 cm) recorded from P_3K_1 which was statistically similar with P_3K_2 (68.45 cm) and P_1K_2 (67.38 cm) whereas, the shortest (57.33 cm) obtained from P_3K_3 which was statistically similar with P_0K_0 and P_1K_0 (58.22 cm).

Table 1. Combined effect of P and K on plant height (cm) of soybean at different DAS

Treatment combinations	Plant height at different DAS					
	30	45	60	75	90	105
P_0K_0	10.28	19.11 b	34.11	49.56 ab	59.89 b	58.22 cd
P_0K_1	10.72	20.17 ab	34.89	50.78 ab	61.89 ab	63.44 b-d
P_0K_2	11.28	20.94 ab	39.78	54.78 ab	60.33 b	64.89 a-d
P_0K_3	11.17	21.50 ab	38.44	49.50 ab	62.67 ab	58.45 cd
P_1K_0	11.67	20.36 ab	35.22	47.78 b	58.33 b	58.22 cd
P_1K_1	11.22	21.64 ab	36.11	54.89 ab	68.00 ab	66.22 a-c
P_1K_2	11.67	22.78 ab	38.22	52.28 ab	66.44 ab	67.38 ab
P_1K_3	11.17	21.11 ab	38.44	49.97 ab	56.89 b	63.33 b-d
P_2K_0	10.94	20.87 ab	35.84	49.93 ab	58.90 b	63.56 b-d
P_2K_1	10.61	21.96 ab	39.73	54.37 ab	64.01 ab	63.55 b-d
P_2K_2	11.00	23.31 ab	41.29	54.21 ab	68.12 ab	63.89 b-d
P_2K_3	10.20	23.75 a	37.06	50.99 ab	62.34 ab	65.67 a-d
P_3K_0	11.83	21.09 ab	37.73	48.18 b	62.23 ab	60.73 b-d
P_3K_1	9.67	22.59 ab	38.12	54.68 ab	72.79 a	72.67 a
P_3K_2	10.39	23.27 ab	40.85	59.71 a	65.24 ab	68.45 ab
P_3K_3	11.17	21.92 ab	38.62	50.62 ab	57.46 b	57.33 d
SE	NS	1.32	NS	3.27	3.30	2.52
CV (%)	10.83	10.55	12.06	10.88	9.10	6.86

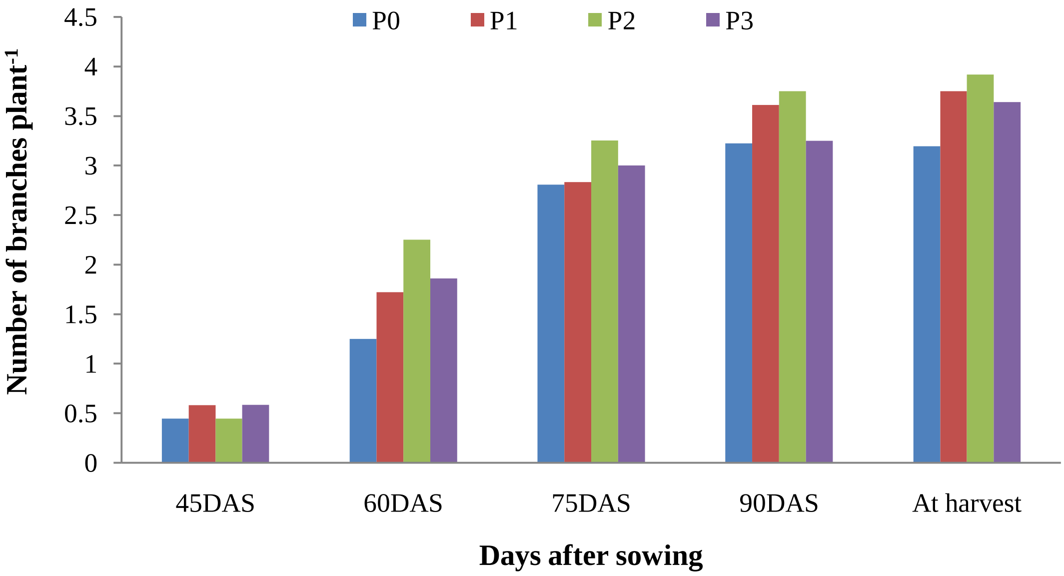
In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability

(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha^{-1}, P_3=250 kg TSP ha^{-1}, K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1} and K_3=180 kg MoP ha^{-1})

4.1.2. Number of branches plant^{-1}

4.1.2.1. Effect of P fertilizer application

Number of branches plant^{-1} of soybean had non-significant effect with P fertilizer application at different DAS and at harvest except 60 DAS (Figure 4 and Appendix V). Numerically the highest number of branches plant^{-1} was obtained from P_2 treatment all over the growth period while, the lowest was found in control treatment. At 60 DAS, the maximum number of branches plant^{-1} (2.25) was obtained from P_2 which was statistically at par with P_3 (1.86) while, the lowest (1.25) recorded from control treatment.

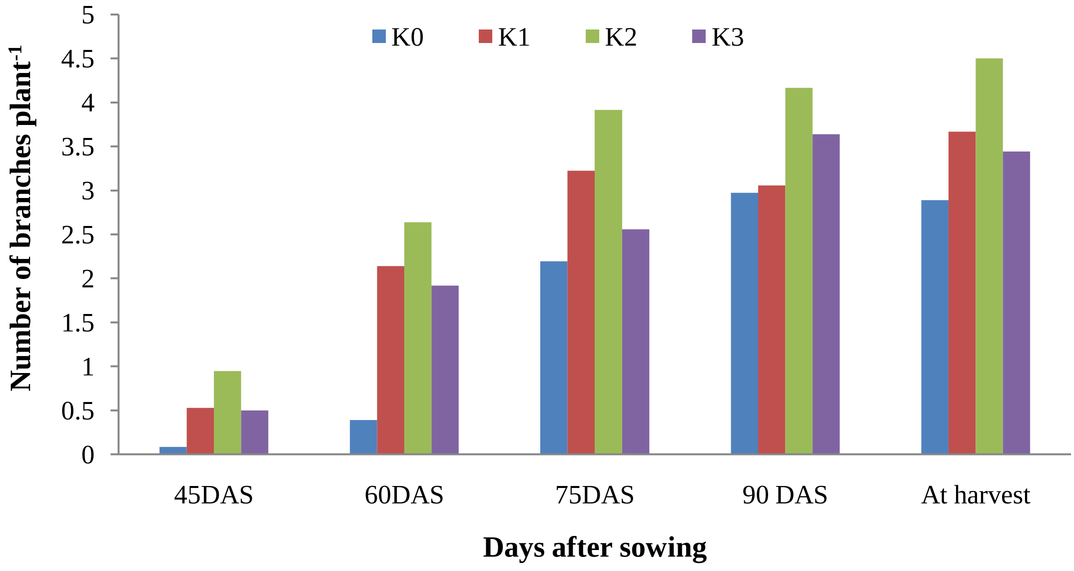


(P_0=No TSP, P_1=100kg TSP ha^{-1}, P_2=175kg TSP ha^{-1}P_3=250 kg TSP ha^{-1})

Figure 4. **Effect of P fertilization level on number of branches plant^{-1} of soybean at different DAS** (SE =NS, 0.13, NS, NS and NS at 45, 60, 75, 90 and at harvest, respectively)

4.1.2.2. Effect of K fertilizer application

Number of branches plant^{-1} of soybean varied significantly due to the different levels of K application at different DAS (Figure 5 and Appendix V). The highest number of branches plant^{-1} was obtained from K_2 treatment all over the growth period whereas, the lowest was found in control (K_0) treatment. Similar findings were recorded by Tariq *et al*. (2001) who reported that the number of branches plant^{-1} was significantly increased by potassium application.



(K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2=120 kg MoP ha^{-1}, K_3=180 kg MoP ha^{-1})

Figure 5. Effect of K fertilization level on number of branches plant^{-1} of soybean at different DAS (SE =0.05, 0.13, 0.19, 0.25 and 0.46 at 45, 60, 75, 90 DAS and at harvest, respectively)

4.1.2.3. Combined effect of P and K fertilizer application

Combined effect of different level of P and K application on number of branches plant^{-1} was also significant at different DAS and at harvest (Table 2). At 45 DAS, maximum number of branches (1.22) was recorded from P_1K_2 which was statistically similar with P_3K_2 (1.00) and P_0K_2 (0.89) and no branches plant^{-1} (0.00) was observed from P_0K_0 which was statistically at par with (0.11) observed from P_1K_0 and P_2K_0. At 60 DAS, maximum number of branches (3.11) was obtained from P_2K_2 which was statistically similar with P_3K_1 (2.89) and P_2K_3 (2.78) and the minimum (0.11) was recorded from P_0K_0 which was statistically similar with P_3K_0 (0.33) and P_1K_0 (0.44). At 75 DAS, maximum number of branches (4.22) was recorded from P_3K_2 which was statistically at par with P_2K_2 (4.00) and P_1K_2 (3.78) and the minimum (2.00) was obtained from P_0K_0 which was statistically similar with (2.11) observed from P_1K_3 and P_3K_0. At 90 DAS, maximum number of branches (4.44) was recorded from P_1K_2 which was statistically similar with P_3K_2 (4.33) and P_0K_3 (4.11) and the minimum (2.00) was obtained from P_0K_0 which was statistically similar with P_3K_0 (2.33) and P_1K_1 (2.67). At harvest, the maximum number of branch (5.34) was recorded from P_1K_2 which was statistically similar with P_2K_2 (4.56) and P_3K_2 (4.33) and the minimum (2.44) was observed from P_1K_0 which was statistically at par with P_3K_0 (2.78) and P_0K_3 (2.98).

Table 2. Combined effect of P and K on number of branches plant^{-1} of soybean at different DAS

Treatment combinations	Number of branches plant^{-1} at different DAS				
	45	60	75	90	At harvest
P_0K_0	0.00 f	0.11 g	2.00 e	2.00 d	3.00 b-d
P_0K_1	0.44 de	0.89 e-g	3.33 a-d	2.67 b-d	3.00 b-d
P_0K_2	0.89 a-c	2.45 ab	3.67a-c	4.11 ab	3.78 b-d
P_0K_3	0.44 de	1.56 c-e	2.22 de	4.11 ab	2.98 b-d
P_1K_0	0.11ef	0.44 g	2.22 de	4.00 a-c	2.44 d
P_1K_1	0.57cd	2.33 a-c	3.22 a-e	2.67 b-d	3.78 b-d
P_1K_2	1.22 a	2.11 b-d	3.78 ab	4.44 a	5.34 a
P_1K_3	0.44 de	2.00 b-d	2.11 de	3.33 a-d	3.44 b-d
P_2K_0	0.11 ef	0.67 fg	2.45 c-e	3.56 a-d	3.33 b-d
P_2K_1	0.44 de	2.45 ab	3.34 a-d	4.11 ab	3.89 a-d
P_2K_2	0.67 b-d	3.11 a	4.00 a	3.78 a-c	4.56 ab
P_2K_3	0.56 cd	2.78 ab	3.22 a-e	3.56 a-d	3.89 a-d
P_3K_0	0.11 ef	0.33 g	2.11 de	2.33 cd	2.78 cd
P_3K_1	0.67 b-d	2.89 ab	3.00 a-e	2.78 a-d	4.00 a-d
P_3K_2	1.00 ab	2.89 ab	4.22 a	4.33 ab	4.33 a-c
P_3K_3	0.56 cd	1.33 d-f	2.67 b-e	3.56 a-d	3.45 b-d
SE	0.11	0.27	0.38	0.49	0.46
CV (%)	36.77	26.23	22.19	24.72	22.02

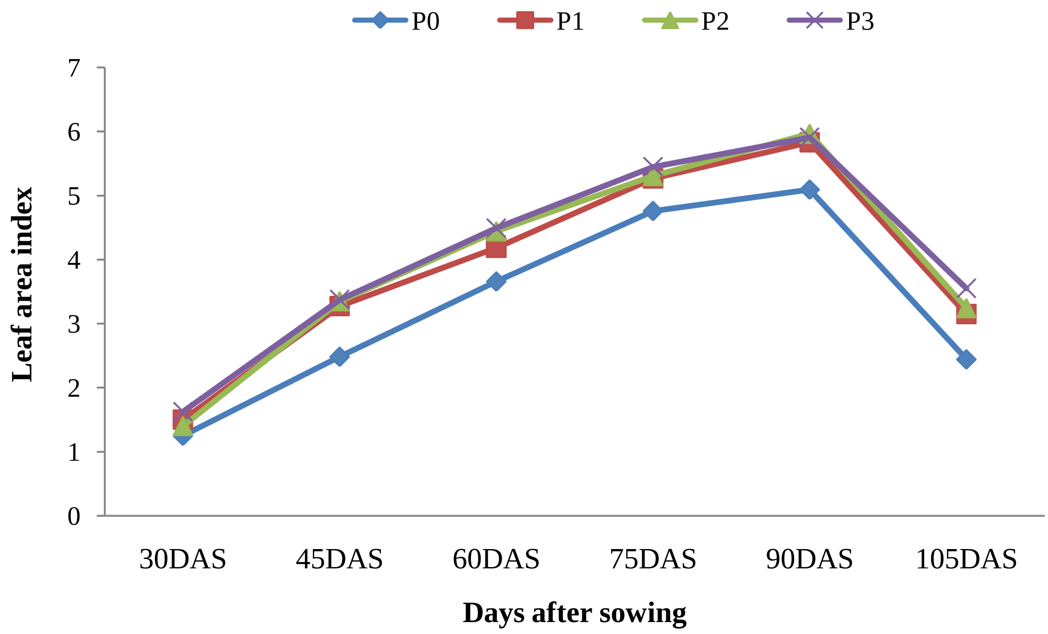
In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability

(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha^{-1}, P_3= 250 kg TSP ha^{-1}, K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1}, and K_3=180kg MoP ha^{-1})

4.1.3. Leaf area index

4.1.3.1. Effect of P fertilizer application

Leaf area index (LAI) was significantly affected by phosphorus at different DAS (Figure 6 and Appendix VI). The highest LAI at 30, 45, 60, 75 and 105 DAS was observed with P_3 treatment and at 90 DAS the highest LAI was obtained with P_2 treatment. The lowest (1.25, 2.48, 3.66, 4.76, 5.09 and 2.44) was obtained where no phosphorus was applied. The decrease in leaf area at low P application might be due to the shortage of nutrients availability and strong competition among the plants (Duncan, 2002) that limited the growth improvement of soybean. These results are in line with those of reported by Malik *et al*. (2006) who stated that the leaf area index varied significantly with P application.

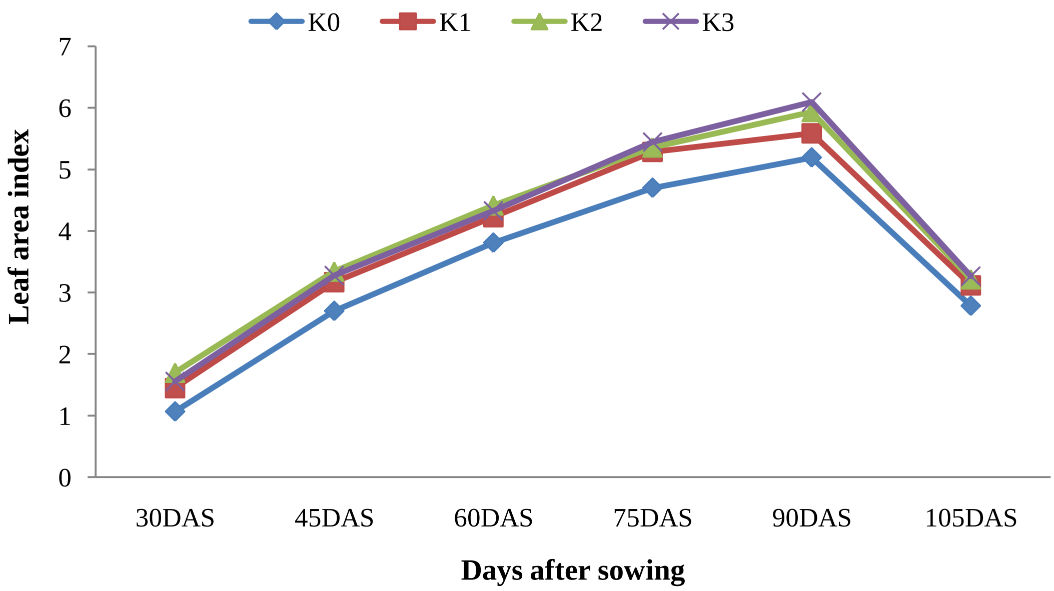


(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175kg TSP ha^{-1}, P_3=250kg TSP ha^{-1})

Figure 6. Effect of P fertilization level on leaf area index of soybean at different DAS (SE=0.082, 0.085, 0.10, 0.090, 0.07 and 0.12 at 30, 45, 60, 75, 90 and 105 DAS, respectively)

4.1.3.2. Effect of K fertilizer application

Leaf area index of soybean varied significantly due to the different levels of K application at different DAS (Figure 7 and Appendix VI). It could be inferred from the figure that K_2 showed the maximum leaf area index (1.70, 3.34 and 4.42) and K_0 showed the minimum (1.07, 2.70 and 3.81) for sampling dates of 30, 45 and 60 DAS respectively but at 60, 75 and 105 DAS showed maximum leaf area index (5.44, 6.09 and 3.27) from K_3 and minimum (4.70, 5.19 and 2.78) obtained from K_0. It is evident from these results that potassium supply in soybean increased LAI that might be better utilization of carbohydrates to form more protoplasm. The cells produced under such conditions tend to be large and to have thin walls (Black, 1967), which may cause an increase in LAI. Leaf area index increased due to increase in dry matter accumulation, with the progressive increase in plant growth under different treatments. With time it reached its maximum value showing significant variation among different treatments and thereafter decline up to harvest of crop (Dar *et al*., 2009). The higher LAI indicate better leaf area expansion. This leaf area expansion helps in subsequent interception and efficient utilization of solar radiation, resulting in increased accumulation of dry matter in leaves and shoots (Satter *et al.*, 2011). Because of osmotic activity of K provides the physical force that expands cells during growth.



(K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2=120 kg MoP ha^{-1}, K_3=180 kg MoP ha^{-1})

Figure 7. Effect of K fertilization level on leaf area index of soybean at different DAS (SE=0.08, 0.08, 0.10, 0.09, 0.07 and 0.12 at 30, 45, 60, 75, 90 and 105 DAS, respectively)

4.1.3.3. Combined effect of P and K fertilizer application

Due to combined effect of different level of P and K application on leaf area index was significantly affected at different DAS (Table 3) At 30 DAS, maximum leaf area index (1.77) was obtained P_3K_3 which was statistically at par with (1.73) obtained from P_3K_2 and P_2K_2 and minimum (0.80) obtained from P_0K_0 which was statistically similar with P_1K_0 (1.00) and (1.30) was obtained from P_3K_0 and $P_2K_{1.}$ At 45 DAS, maximum leaf area index (3.70) was found from P_2K_2 which was statistically at par with P_3K_2 (3.67) and (3.55) obtained from P_3K_1 and P_3K_3 and minimum (2.23) observed from P_0K_0 which was statistically similar with P_0K_1 (2.47) and P_0K_2 (2.57). At 60 DAS, maximum leaf area index (4.63) was recorded from P_2K_2 which was statistically at par with (4.60) obtained from P_2K_2, P_3K_2 and P_3K_3 and minimum (3.17) found from control (P_0K_0) treatment which was statistically similar with P_0K_1 (3.57) and P_1K_0 (3.73). At 75 DAS, maximum leaf area index (5.73) was observed from P_3K_3 treatment combination which was statistically similar with P_2K_3 (5.70) and P_3K_2 (5.63) and minimum (4.10) obtained from P_0K_0. At 90 DAS, maximum leaf area index (6.43) was obtained from P_2K_3 which was statistically similar with P_2K_2 (6.20) and P_3K_2 (6.13) and minimum (4.20) recorded from P_0K_0. At 105 DAS, maximum leaf area index (3.67) obtained from P_3K_2 and P_3K_3 which was statistically similar with (3.50) obtained from P_3K_1 and P_2K_3 and minimum (2.10) observed from P_0K_0 which was statistically at par with P_0K_1 (2.47) and P_0K_3 (2.57).

Table 3. Combined effect of P and K on leaf area index of soybean at different DAS

Treatment combinations	Leaf area index at different DAS					
	30	45	60	75	90	105
P_0K_0	0.80 e	2.23 e	3.17 e	4.10 g	4.20 f	2.10 f
P_0K_1	1.20 b-e	2.47 de	3.57 de	4.90 ef	4.93 e	2.47 ef
P_0K_2	1.63 a-c	2.57 de	3.97 a-d	5.03 c-f	5.47 d	2.63 c-f
P_0K_3	1.37 a-d	2.67de	3.93 b-d	5.00 d-f	5.77 b-d	2.57 d-f
P_1K_0	1.00 de	2.83 cd	3.73 c-e	5.10 b-f	5.53 d	2.90 a-e
P_1K_1	1.60 a-c	3.23 a-c	4.37 a-c	5.33 a-f	5.80 b-d	3.17 a-e
P_1K_2	1.70 a-c	3.43 ab	4.50 ab	5.30 a-f	5.93 b-d	3.20 a-e
P_1K_3	1.70 a-c	3.60 a	4.13 a-d	5.33 a-f	6.07 a-c	3.33 a-d
P_2K_0	1.17 c-e	2.97 b-d	4.07 a-d	4.73 f	5.53 d	2.77 b-f
P_2K_1	1.30 a-e	3.43 ab	4.47 ab	5.33 a-f	5.70 cd	3.33 a-d
P_2K_2	1.73 ab	3.70 a	4.60 ab	5.47 a-e	6.20 ab	3.37 a-c
P_2K_3	1.40 a-d	3.30 a-c	4.63 a	5.70 ab	6.43 a	3.50 ab
P_3K_0	1.30 a-e	2.77c-e	4.27 a-c	4.87 ef	5.50 d	3.37 a-c
P_3K_1	1.70 a-c	3.53 a	4.50 ab	5.57 a-d	5.90 b-d	3.50 ab
P_3K_2	1.73 ab	3.67 a	4.60 ab	5.63 a-c	6.13 a-c	3.67 a
P_3K_3	1.77 a	3.53 a	4.60 ab	5.73 a	6.10 a-c	3.67 a
SE	0.16	0.17	0.20	0.18	0.15	0.23
CV (%)	19.57	9.38	8.35	6.04	4.46	12.94

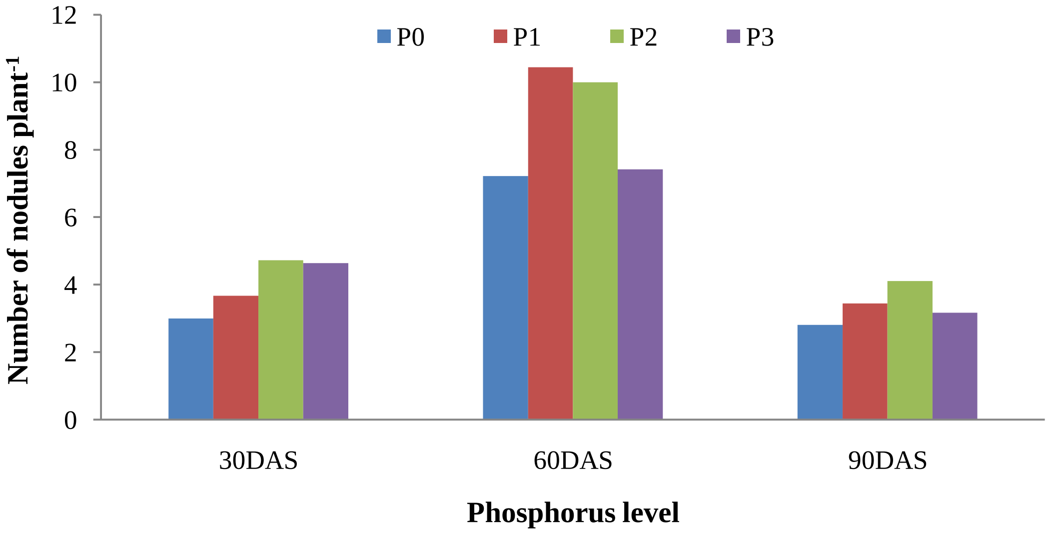
In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability

(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha^{-1}, P_3= 250 kg TSP ha^{-1} K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1} and K_3=180 kg MoP ha^{-1})

4.1.4. Number of nodules plant^{-1}

4.1.4.1. Effect of P fertilizer application

Number of nodules plant^{-1} of soybean varied significantly due to the different levels of P application at different DAS (Figure 8 and Appendix VII). It could be inferred from the figure that P_2 showed the maximum number of nodules (4.72, 9.99 and 4.11) and P_0 showed the minimum (2.99, 7.22 and 2.80) for sampling dates of 30, 60 and 90 DAS, respectively. A reduction in nodulation with high P application rates is due to imbalance which results in an inadequate release of P to plants from insoluble and fixed forms. Islam *et al*. (2004) reported that the number of nodules plant^{-1} increased from 45 to 80 DAS and after that it decreased severely. The positive effect of P application on nodule number was confirmed by Tsvetkova and Georgiew (2003). The data from their experiment showed that nodule number decreased by almost 50% in P deficient plants. Rotaru (2010) confirmed that the nodulation process respond significantly to supplementary P nutrition.

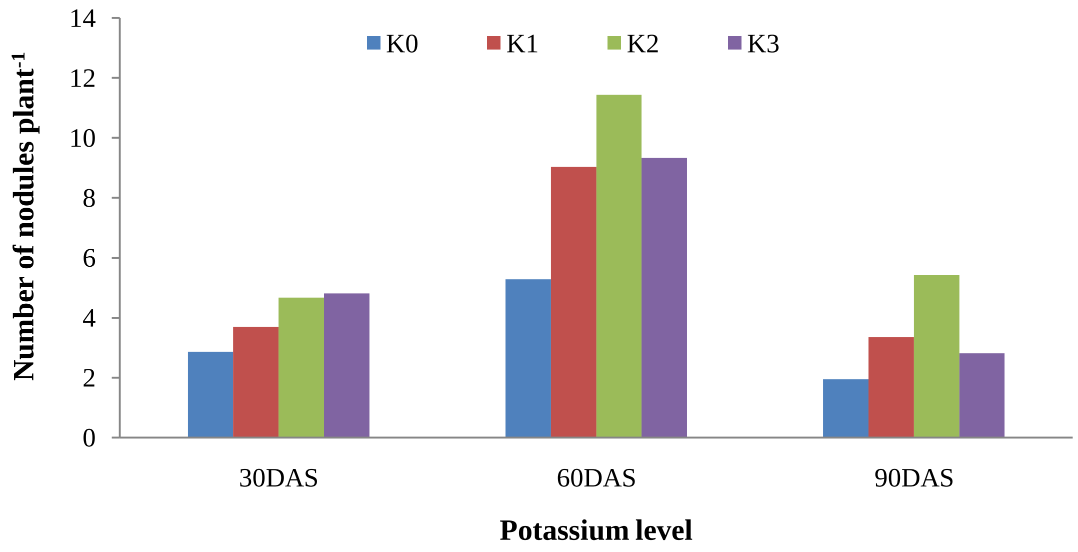


(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha^{-1}, P_3=250 kg TSP ha^{-1})

Figure 8. Effect of P fertilization level on number of nodules plant^{-1} of soybean at different DAS (SE =0.21, 0.86, and 0.25 at 30, 60 and 90 DAS, respectively)

4.1.4.2. Effect of K fertilizer application

Number of nodules plant^{-1} of soybean varied significantly due to the different levels of K application at different DAS (Figure 9 and Appendix VII). It could be inferred from the figure that K_2 showed the maximum number of nodules (11.44 and 5.42) and K_0 showed the minimum (5.28 and 1.95) for sampling dates of 60 and 90 DAS respectively. At 30 DAS, the maximum number of nodules plant^{-1} (4.81) was obtained from K_3 treatment and minimum (2.86) obtained where no potassium was applied.



(K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2=120 kg MoP ha^{-1}, K_3=180 kg MoP ha^{-1}

Figure 9. Effect of K fertilization level on number of nodules plant^{-1} of soybean at different DAS (SE =0.21, 0.86, and 0.25 at 30, 60 and 90 DAS, respectively)

4.14.3. Combined effect of P and K application

Combined effect of different level of P and K application on number of nodules plant^{-1} was also significant at different DAS (Table 4). At 30 DAS, maximum number of nodules (6.44) was recorded from P_2K_3 which was statistically similar with P_3K_3 (5.56) and (5.22) was obtained from P_2K_2 and P_3K_2 and minimum (2.11) was observed from P_0K_0 which was statistically at par with P_0K_1 (2.78) and P_1K_0 (2.78). At 60 DAS, maximum number of nodules (13.22) was obtained from P_1K_2 which was statistically similar with P_1K_3 (12.11) and P_2K_1 (12.00) and minimum (3.67) was recorded from P_0K_0 which was statistically similar with P_3K_0 (5.33) and P_2K_0 (5.67). At 90 DAS, maximum number of nodules (7.11) was recorded from P_1K_2 and minimum (1.33) was obtained from P_1K_0 which was statistically similar with P_0K_0 (1.44) and P_1K_3 (1.78).

Table 4. Combined effect of P and K on number of nodules plant^{-1} of soybean at different DAS

Treatment combinations	Number of nodules plant^{-1} at different DAS		
	30	60	90
P_0K_0	2.11 g	3.67e	1.44 f
P_0K_1	2.78 fg	6.22 c-e	2.78 d-f
P_0K_2	3.33 e-g	11.11 a-d	4.22 b-d
P_0K_3	3.78 d-f	7.89 a-e	2.78 d-f
P_1K_0	2.78 fg	6.44 b-e	1.33 f
P_1K_1	3.56 d-f	10.00 a-d	3.56 c-e
P_1K_2	4.89 b-d	13.22 a	7.11 a
P_1K_3	3.45 e-g	12.11 ab	1.78 f
P_2K_0	3.11e-g	5.67 de	2.89 d-f
P_2K_1	4.11 c-f	12.00 a-c	4.11 b-d
P_2K_2	5.22 a-c	11.67 a-c	5.33 b
P_2K_3	6.44 a	10.67a-d	4.11 b-d
P_3K_0	3.44 e-g	5.33 de	2.11 ef
P_3K_1	4.33 b-e	7.89 a-e	2.99 d-f
P_3K_2	5.22 a-c	9.78 a-d	5.00 bc
P_3K_3	5.56 ab	6.67 b-e	2.56 d-f
SE	0.42	1.72	0.50
CV (%)	18.16	33.02	25.79

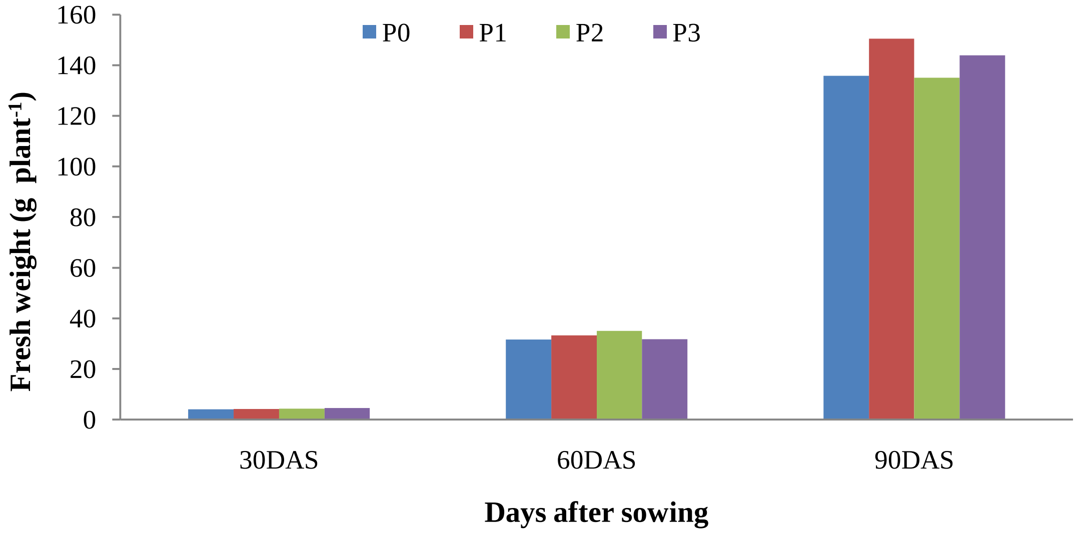
In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability

(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha^{-1}, P_3=250 kg TSP ha^{-1}. K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1} and K_3=180 kg MoP ha^{-1}

4.1.5. Fresh weight

4.1.5.1. Effect of P fertilizer application

Fresh weight of soybean had non-significant effect with different levels of P application at different DAS (Figure 10 and Appendix VIII). At 30 DAS, numerically the maximum fresh weight (4.53 g) was recorded from P_3 and the minimum (4.05 g) observed without phosphorus application. At 60 DAS, numerically maximum weight (35.08 g) was obtained from P_2 while, the minimum (31.56 g) obtained from control treatment. At 90 DAS, numerically maximum weight was recorded from P_1 (150.5 g) whereas, the lowest (135.1 g) obtained from P_2 treatment.

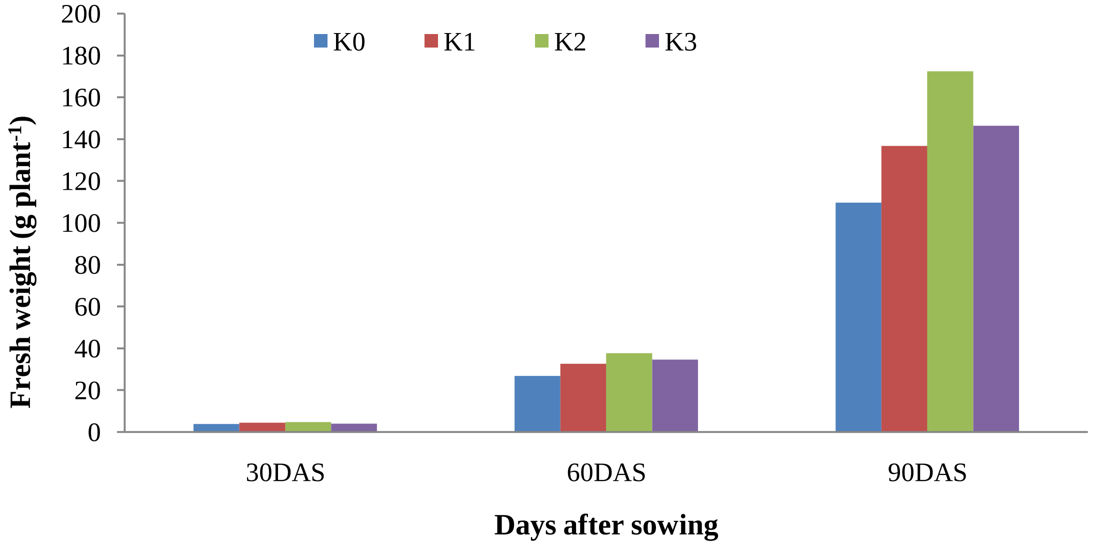


(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha^{-1}, P_3=250 kg TSP ha^{-1}

Figure 10. Effect of P fertilization level on fresh weight of soybean at different DAS (SE =NS, NS and NS at 30, 60 and 90 DAS, respectively)

4.1.5.2. Effect of K fertilizer application

Fresh weight of soybean varied significantly due to the different levels of K application at different DAS (Figure 11 and Appendix VIII). It could be inferred from the figure that K_2 showed the maximum fresh weight (4.82, 37.72 and 172.5 g) and K_0 showed the minimum (3.83, 26.74 and 109.7 g) for sampling dates of 30, 60 and 90 DAS.



(K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2=120 kg MoP ha^{-1}, K_3=180 kg MoP ha^{-1})

Figure 11. Effect of K fertilization level on fresh weight of soybean at different DAS (SE =0.23, 2.26 and 7.56 at 30, 60 and 90 DAS, respectively)

4.1.5.3. Combined effect of P and K fertilizer application

Combined effect of different level of P and K application on fresh weight was also significant at different DAS (Table 5). At 30 DAS, maximum fresh weight (5.30 g) was recorded from P_3K_2 which was statistically similar with the P_2K_2 (5.27 g) and P_1K_2 (4.40 g) and minimum (3.40 g) obtained from P_0K_0. At 60 DAS, maximum fresh weight (42.17 g) was recorded from P_2K_2 which was statistically similar with the P_2K_3 (40.00 g) and P_3K_2 (37.13 g) and lowest (23.50 g) was recorded from P_0K_0 which was statistically similar P_2K_0 (25.10 g). At 90 DAS, maximum fresh weight (210.2 g) was obtained from P_2K_2 which was statistically similar with the P_1K_2 (181.6 g) and minimum (102.8 g) was obtained from P_3K_0 which was statistically at par with P_0K_0 (109.2 g).

Table 5. Combined effect of P and K on fresh weight (g) of soybean at different DAS

Treatment combinations	Fresh weight (g plant^{-1}) at different DAS		
	30	60	90
P_0K_0	3.40 b	23.50 c	109.2 d-f
P_0K_1	4.63 ab	32.50 a-c	135.6 b-f
P_0K_2	4.30 ab	36.40 a-c	133.2 b-f
P_0K_3	3.87 ab	33.83 a-c	165.0 a-c
P_1K_0	3.87 ab	30.67 a-c	131.9 b-f
P_1K_1	4.33 ab	34.07 a-c	141.0 b-f
P_1K_2	4.40 ab	35.17 a-c	181.6 ab
P_1K_3	3.93 ab	33.10 a-c	147.4 b-e
P_2K_0	3.83 ab	25.10 bc	94.69 f
P_2K_1	4.33 ab	33.03 a-c	120.9 c-f
P_2K_2	5.27 a	42.17 a	210.2 a
P_2K_3	3.83 ab	40.00 ab	114.6 c-f
P_3K_0	4.23 ab	27.70 a-c	102.8 ef
P_3K_1	4.27 ab	31.07 a-c	149.8 b-e
P_3K_2	5.30 a	37.13 a-c	164.9 a-c
P_3K_3	4.33 ab	31.27 a-c	158.4 b-d
SE	0.47	4.52	15.13
CV (%)	19.05	23.80	18.54

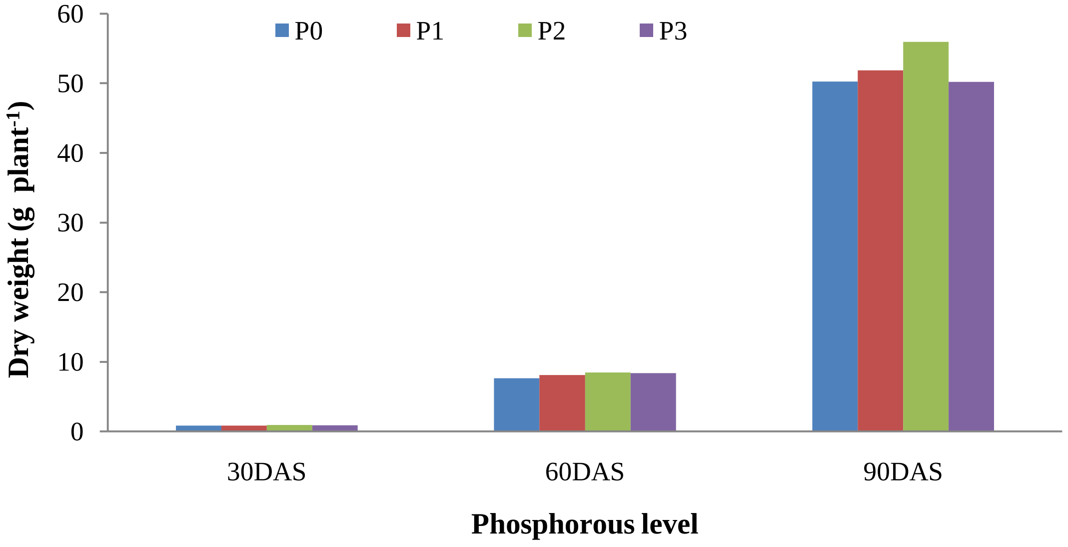
In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability

(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha^{-1}, P_3=250 kg ha^{-1}, K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1} and K_3=180 kg MoP ha^{-1})

4.1.6. Dry weight

4.1.6.1. Effect of P fertilizer application

Dry weight of soybean had non-significant effect with different levels of P application at different DAS (Figure 12 and Appendix IX). This figure indicated that numerically the maximum dry weight (0.93 g and 8.47 g) was recorded from P_2 whereas, the minimum (0.84 g and 7.61 g) was observed from P_0 for sampling dates of 30 and 60 DAS. These results are supported by Vieira *et al.* (1980) who reported that application of phosphorus increase plant weight but effect was not significant between the different phosphorus rates but contradictory results were obtained by Begum *et al.* (2015).

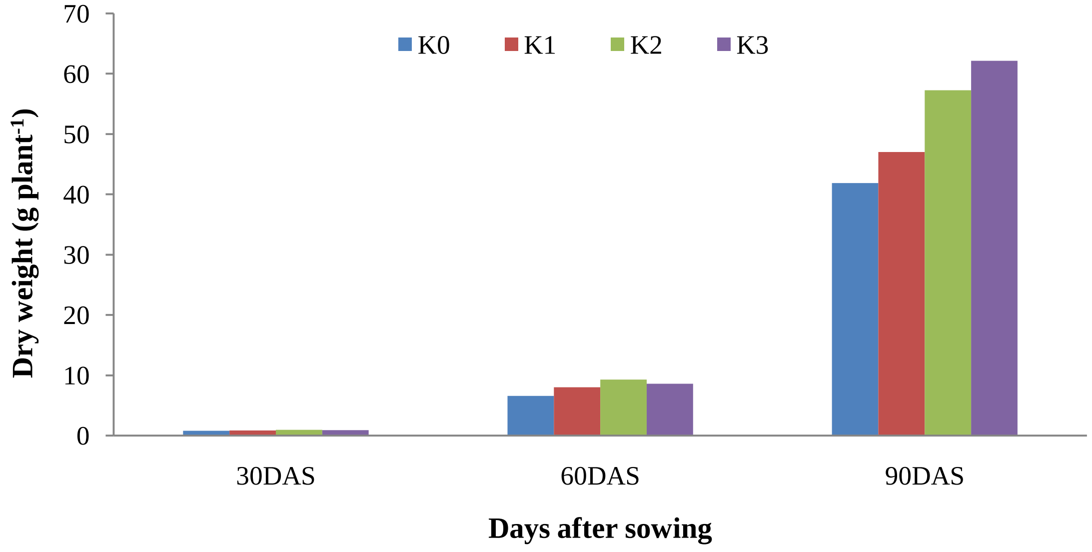


(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha^{-1}, P_3=250 kg TSP ha^{-1})

Figure 12. Effect of P fertilization level on dry weight of soybean at different DAS (SE =NS, NS and NS at 30, 60 and 90 DAS, respectively)

4.1.6.2. Effect of K fertilizer application

Dry weight of soybean varied significantly due to the different levels of K application at different DAS (Figure 13 and Appendix IX). It could be inferred from the figure that K_2 showed the maximum dry weight plant^{-1} (0.96 g and 9.28 g) and K_0 showed the minimum (0.78 g and 6.59 g) for sampling dates of 30 and 60 DAS respectively. At 90 DAS, maximum dry weight plant^{-1} (62.15 g) obtained from K_3 whereas, minimum (41.85 g) obtained from K_0. These results are unconformity with the findings of Shehu *et al*. (2010) who reported that dry weight was not significantly influenced by K fertilizer application.



(K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2=120 kg MoP ha^{-1} K_3=180 kg MoP ha^{-1})

Figure 13. Effect of K fertilization level on dry weight of soybean at different DAS (SE =0.04, 0.57 and 2.84 at 30, 60 and 90 DAS, respectively)

4.1.6.3. Combined effect of P and K fertilizer application

Combined effect of different level of P and K application on dry weight was also significant at different DAS except 30 DAS (Table 6). At 30 DAS, numerically maximum dry weight (1.02 g) was obtained from P_2K_2 and minimum (0.73 g) recorded from P_0K_0. At 60 DAS, maximum dry weight (10.21 g) obtained from P_2K_2 which was statistically at par with P_3K_2 (9.77 g) and P_2K_3 (9.37 g) and minimum (6.05 g) observed from P_3K_0 which was statistically similar with P_2K_0 (6.19 g) and P_0K_0 (6.26 g). At 90 DAS, maximum dry weight (69.73 g) recorded from P_0K_2 which was statistically similar with P_2K_3 (68.87 g) and P_3K_3 (67.57 g) and minimum (38.10 g) observed from P_1K_0 which was statistically at par with P_0K_0 (39.10 g) and P_3K_0 (40.17 g).

Table 6. Combined effect of P and K on dry weight (g) of soybean at different DAS

Treatment combinations	Dry weight (g plant^{-1}) at different DAS		
	30	60	90
P_0K_0	0.73	6.26 b	39.10 c
P_0K_1	0.83	7.66 ab	40.20 c
P_0K_2	0.90	8.75 ab	69.73 a
P_0K_3	0.89	7.79 ab	52.03 a-c
P_1K_0	0.77	7.87 ab	38.10 c
P_1K_1	0.79	8.01 ab	52.43 a-c
P_1K_2	0.97	8.38 ab	56.83 a-c
P_1K_3	0.87	8.05 ab	60.13 ab
P_2K_0	0.85	6.19 b	50.03 bc
P_2K_1	0.86	8.11 ab	54.63 a-c
P_2K_2	1.02	10.21 a	50.27 bc
P_2K_3	0.98	9.37 ab	68.87 ab
P_3K_0	0.78	6.05 b	40.17 c
P_3K_1	0.83	8.34 ab	40.90 c
P_3K_2	0.97	9.77 ab	52.13 a-c
P_3K_3	0.88	9.28 ab	67.57 ab
SE	NS	1.15	5.68
CV (%)	17.64	24.44	18.90

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability

(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha^{-1}, P_3=250 kg TSP ha$^{-1.}$ K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1} and K_3=180 kg MoP ha^{-1})

4.2. Yield contribution characters of soybean

4.2.1. Filled pods plant^{-1}

4.2.1.1. Effect of P fertilizer application

The number of filled pods plant^{-1} was the highest in the P_2 treatment which was significantly highest than those of other treatments (Table 7). The maximum number of pods plant^{-1} of soybean (51.14) was recorded from P_2 which was statistically at par with P_1 (49.83) P_3 (43.17) and whereas, the lowest (39.34) was observed from P_0. The present results supports the reports of Singh and Bajpai (1990) who observed that increasing phosphorus rate increased the number of pods plant^{-1} up to a certain limit and then decreased. The significant response of number of pods to P application obtained in this study differ from the reports of Olowe and Busari (2000) and Muhamman *et al*. (2009) who reported non-significance at 60 and 45 kg P ha^{-1} respectively but corroborates with the reports of Deshmukh *et al*. (1990).

Table 7. Effect of P on filled pods plant^{-1}, length of pod, number of seeds pod^{-1}, 1000-seed weight of soybean

Effect of phosphorus	Filled pods plant^{-1}	Length of pod (cm)	Number of seeds pod^{-1}	1000-seed weight (g)
P_0	39.34 b	2.99	1.71 c	101.5 c
P_1	49.83 a	3.03	2.41 b	105.3 ab
P_2	51.14 a	3.05	2.98 a	106.2 a
P_3	43.17 ab	3.01	2.38 b	103.6 b
SE	3.33	NS	0.07	0.58
CV (%)	30.49	4.19	11.94	1.98

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability

(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha^{-1}, P_3=250 kg TSP ha^{-1})

4.2.1.2. Effect of K fertilizer application

Potash levels affected the number of filled pods plant^{-1} significantly (Table 8).The maximum number of pods plant^{-1} of soybean (53.92) was recorded from K_2 which was statistically similar with K_1 (50.90) and the lowest (35.79) was observed in plots where no potassium was applied which was statistically at par with K_3 (42.87). Ali *et al*. (1996) also reported that number of pods plant^{-1} was influenced significantly by potassium application. The present results are consistent with the findings of Hussain *et al.* (2011).

Table 8. Effect of K on filled pods plant^{-1}, length of pod, number of seeds pod^{-1}, 1000-seed weight of soybean

Effect of potassium	Filled pods plant^{-1}	Length of pod (cm)	Number of seeds pod^{-1}	1000-seed weight
K_0	35.79 c	2.96 b	2.26 b	101.2 c
K_1	50.90 ab	3.02 ab	2.37 ab	104.9 ab
K_2	53.92 a	3.09 a	2.50 a	106.4 a
K_3	42.87 bc	3.01 ab	2.35 ab	104.1 b
SE	3.33	0.04	0.07	0.58
CV (%)	25.14	4.46	10.52	1.93

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability

(K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1} and K_3=180 kg MoP ha^{-1})

4.2.1.3. Combined effect of P and K fertilizer application

Combined effect of P and K application had significant effect on filled pods plant^{-1} of soybean (Table 9). The highest number of pods (63.00) was recorded from P_2K_2 which was statistically similar with P_2K_1 (61.11) and P_1K_2 (56.78) whereas, the lowest (32.15) was obtained from P_0K_0 which was statistically at par with P_1K_0 (35.56) and P_2K_0 (37.11). The present results are agrees with the findings of Xiang *et al*. (2012) who observed that combination of P x K indicated that increasing amount of K application from 0 to 112.5 kg ha^{-1} increase pods plant^{-1}. Similar trend was also observed at the rate of P application 0 to 17 kg ha^{-1}.

4.2.2 Length of pod (cm)

4.2.2.1. Effect of P fertilizer application

The effect of phosphorus on length of pods was non-significant (Table 7). Numerically the highest length of pod (3.05 cm) was recorded from P_2 treatment and the lowest (2.99 cm) was found in control (P_0) treatment. Sardana and Verma (1987) were also found the same results.

4.2.2.2. Effect of K fertilizer application

Length of pod of soybean showed significant variation (Table 8).The highest pod length (3.09 cm) was recorded from K_2 which was statistically similar with K_1 (3.02 cm) and the lowest (2.96 cm) was obtained from K_0 which was statistically at par with K_3 (3.01 cm) and K_1 (3.02 cm). This result agrees with Patel and Patel (1991) who revealed that pod length varied significantly at different levels of K application.

4.2.2.3. Combined effect of P and K fertilizer application

Length of pod had non-significant effect combination of P and K application (Table 9). Numerically the maximum length of pod (3.16 cm) was obtained from P_2K_2 whereas; the lowest (2.92 cm) was recorded from P_3K_0. Shehu *et al*. (2010) found that combination of P and K showed non-significant effect on length of pod which was supported this experiment.

4.2.3 No of seed pod^{-1}

4.2.3.1. Effect of P fertilizer application

Number of seed pod^{-1} of soybean showed significant variation (Table 7). The maximum number of seeds pod^{-1} (2.98) was recorded from P_2 treatment and minimum (1.71) was obtained from control (P_0) treatment. Hernandez and Cuevas (2003) also reported significant high number of seeds pod^{-1} was recorded when 100 kg P_2O_5 ha^{-1} was applied and minimum number of seeds pod^{-1} when no phosphorus was applied. These results confirm the findings of Tomar *et al.* (2004) who observed that significant differences in number of seeds pod^{-1} when different levels of phosphorus were applied.

4.2.3.2. Effect of K fertilizer application

Number of seeds pod^{-1} affected of significantly by various K levels (Table 8). The maximum number of seed pod^{-1} of soybean (2.50) was recorded from K_2 which was statistically at par with K_1 (2.37) and K_3 (2.35) while, lowest (2.26) was observed from K_0. K application not only enhanced the availability of other nutrient but also increased the transportation of photosynthates; protein synthesis from source to sink might be the main reason for increase in number of seeds. Similar results were obtained by Ali *et al.* (1996).

4.2.3.3. Combined effect of P and K fertilizer application

Due to combined effect of different level of P and K fertilizer application on number of seeds pod^{-1} of soybean was significantly affected (Table 9). The maximum number of seed pod^{-1} of soybean (3.11) was recorded from P_2K_2 which was statistically similar with P_2K_3 (3.04) and the P_2K_1 (2.93) and lowest (1.62) was observed from P_0K_0 which was statistically at par with P_0K_3 (1.67) and the P_0K_1 (1.71).

4.2.4. 1000- seed weight

4.2.4.1. Effect of P fertilizer application

1000-seed weight had significant effect on different level of P application (Table 7). The highest weight (106.2 g) was obtained from P_2 which was statistically at par with P_1 (105.3 g) while, the lowest (101.5 g) was recorded from control (P_0) treatment. These results are similar from the findings of Devi *et al.* (2012) who observed that significant variation on 1000-seed weight at different phosphorus levels.

4.2.4.2. Effect of K fertilizer application

Significant differences of 1000-seed weight were also noted (Table 8). As for as different treatments are concerned the application of 120 kg MoP ha^{-1} (K_2) resulted in maximum 1000-seed weight which was statistically similar with 60 kg MoP ha^{-1} (K_1) and minimum (101.2 g) seed weight was recorded in plots where no potash was applied. These results agreed with Dixit *et al*. (2011) who reported the weight of 1000-seed weight significantly increased with K application.

4.2.4.3. Combined effect of P and K fertilizer application

Combined effect of P and K fertilizer application on 1000-seed weight of soybean showed significant effect (Table 9). The maximum (109.1 g) seed weight was obtained from P_2K_2 which was statistically at par with P_1K_2 (107.5 g) whereas; the lowest (96.56 g) was recorded from P_0K_0. These results are differing with Mokoena (2013) who observed that P X K combination effect was not significant in terms of 1000-seed weight. Shehu *et al*. (2010) also found the same results.

Table 9. Combined effect of P and K on filled pods plant^{-1}, length of pod, number of seeds pod^{-1}, 1000-seed weight of soybean

Treatment combinations	Filled pods plant^{-1}	Length of pod(cm)	Number of seed pod^{-1}	1000-seed weight
P_0K_0	32.15 c	2.92	1.62 f	96.56 f
P_0K_1	40.59 a-c	3.02	1.71 f	103.8 b-e
P_0K_2	46.48 a-c	3.03	1.85 ef	104.2 b-e
P_0K_3	38.15 bc	3.02	1.67 f	101.6 e
P_1K_0	35.56 bc	2.98	2.33 d	102.4 de
P_1K_1	54.8 a-c	3.04	2.39 cd	105.8 a-d
P_1K_2	56.78 ab	3.05	2.55 b-d	107.5 ab
P_1K_3	52.1 a-c	3.03	2.38 cd	105.3 b-e
P_2K_0	37.11bc	2.99	2.84 a-c	103.6 b-e
P_2K_1	61.11 a	3.02	2.93 ab	106.8 a-c
P_2K_2	63.00 a	3.16	3.11 a	109.1 a
P_2K_3	43.3 a-c	2.99	3.04 a	105.3 b-e
P_3K_0	38.33 bc	2.92	2.23 de	102.4 de
P_3K_1	47.0 a-c	3.01	2.47 b-d	103.3 c-e
P_3K_2	49.4 a-c	3.11	2.50 b-d	104.9 b-e
P_3K_3	37.89 bc	2.98	2.32 d	104.0 b-e
SE	6.66	NS	0.14	1.159
CV (%)	25.14	4.46	10.52	1.93

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability

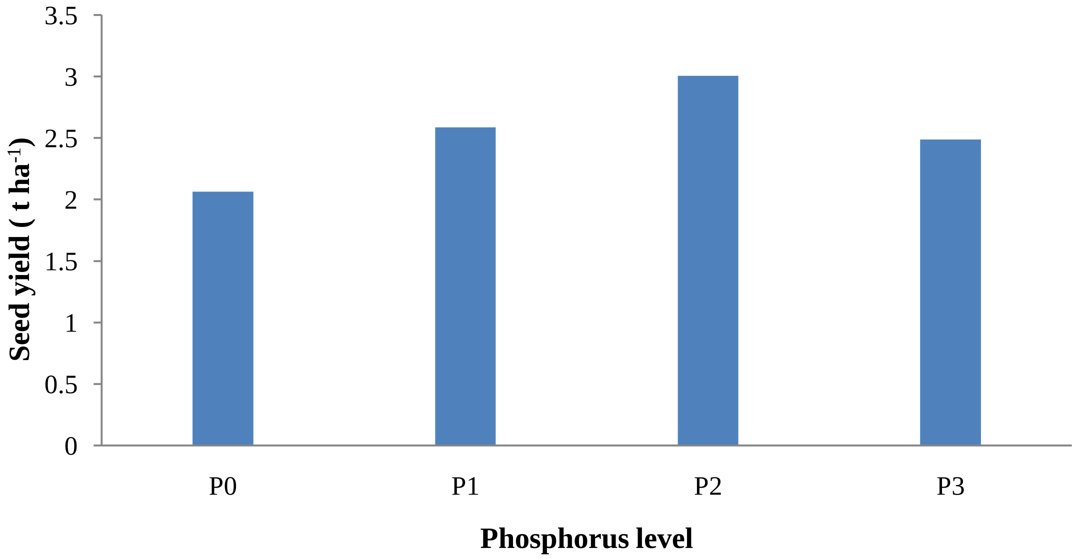
(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha^{-1}, P_3=250 kg TSP ha^{-1}, K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1} and K_3=180 kg MoP ha^{-1})

4.3. Yield and harvest index

4.3.1. Seed yield (t ha^{-1})

4.3.1.1. Effect of P fertilizer application

The highest seed yield (3.01 t ha^{-1}) was produced when the crop was fertilized with 175 kg TSP ha^{-1} (P_2) and the lowest (2.06 t ha^{-1}) was recorded in the treatment of 0 kg TSP ha^{-1} (Figure 14 and Appendix XI). The present results are similar to Ali *et al*. (2004) and Farani (1988) who reported an increase in seed yield due to increased levels of P. The increase in seed yield might be due to more number of pods plant^{-1}, seeds pod^{-1} and/or 1000-seed weight. The low yield of soybean grain at lower levels of phosphorus was probably due to lesser magnitude of phosphorus response. Increasing soybean seed yield with the increasing level of phosphorus were also observed by Iibas and Sahn (2005), Tapas and Gupta (2005), Landge et al. (2002), Umale et al. (2002), and Stefanescu and Palanciuc (2000).

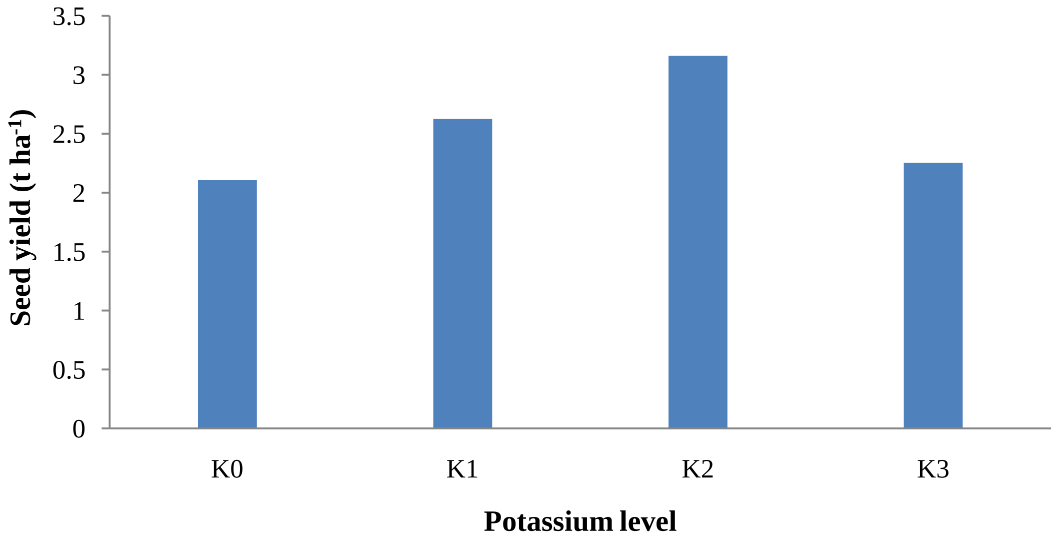


(P_0= 0 kg TSP ha^{-1}, P_1= 100 kg TSP ha^{-1}, P_2= 175 kg TSP ha^{-1}, P_3= 250 kg TSP ha^{-1})

Figure 14. Effect of phosphorus on seed yield (t ha^{-1}) of soybean (SE = 0.15)

4.3.1.2. Effect of K fertilizer application

Seed yield of soybean varied significantly with different level of K application (Figure 15 and Appendix XI). The maximum yield of soybean (3.16 t ha^{-1}) was recorded from K_2 and the minimum (2.16 t ha^{-1}) was observed K_0 which was statistically similar with K_3 (2.25 t ha^{-1}). The possible reason could be that the balance K gave favorable environment to the plants, which helped in the absorption of more nutrients and hence more yield, was produced (Ahmad *et al*., 2000). Decrease in the yield and yield components in control treatment is mainly due to a reduction in the seed set in the fruit which may be attributed to decrease in number of seeds pod^{-1} and 1000-seed weight (El-Hadidi *et al*., 2007). Similar findings were discussed by Dixit *et al*. (2011) who clearly indicated that K is known as one of the nutrients which are closely involved in metabolic processes and improved yield. The higher seed yield due to K fertilizer application was also in agreement with Deshmukh *et al*. (1994) who obtained the highest soybean yield where K was applied. Mir *et al*. (2010) also reported that seed yield increased with increasing amounts of potassium.



(K_0= 0 kg MoP ha^{-1}, K_1=60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1}, K_3= 180 kg MoP ha^{-1})

Figure 15. Effect of potassium on seed yield (t ha^{-1}) of soybean (SE = 0.15)

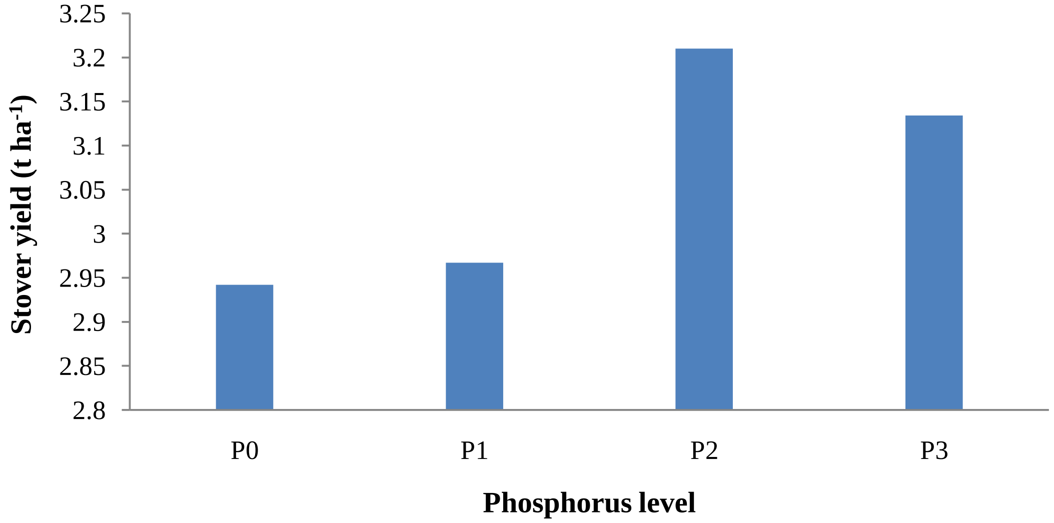
4.3.1.3. Combined effect of P and K fertilizer application

Combined effect of P and K application had significant effect on seed yield of soybean (Table 10). The highest yield (3.67 t ha^{-1}) was recorded from P_2K_2 which was statistically similar with P_3K_2 (3.42 t ha^{-1}) and P_2K_1 (3.13 t ha^{-1}) and the lowest (1.78 t ha^{-1}) was obtained from P_0K_0 which was statistically at par with P_0K_3 (1.88 t ha^{-1}) and P_3K_0 (1.97 t ha^{-1}).

4.3.2. Stover yield (t ha^{-1})

4.3.2.1. Effect of P fertilizer application

Stover yield of soybean had non-significant with different level of P application (Figure 16 and Appendix XI). Numerically the maximum stover yield of soybean (3.21 t ha^{-1}) was recorded from P_2 while, the minimum (2.94 t ha^{-1}) was obtained from control (P_0) treatment. Devi *et al.* (2012) found that stover yield significantly varied with phosphorus and the maximum stover yield was obtained from 80 kg P_2O_5 ha^{-1} followed by 60 kg P_2O_5 ha^{-1} while, the lowest was obtained from control treatment. The present results are corroborates with Ali *et al.* (2013) who reported that found P had non-significant effect on stover yield of soybean.

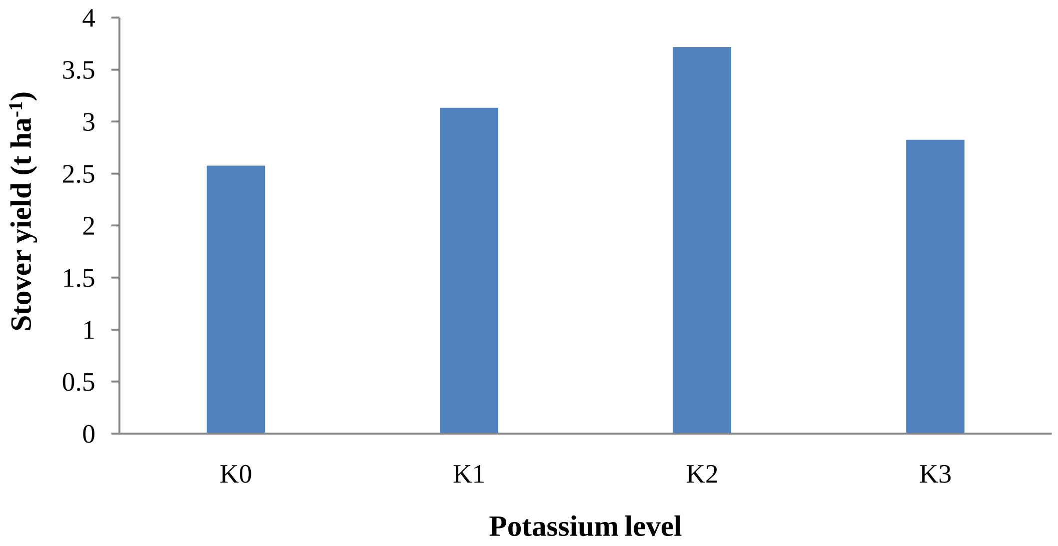


(P_0= 0 kg TSP ha^{-1}, P_1= 100 kg TSP ha^{-1}, P_2= 175 kg TSP ha^{-1}, P_3= 250 kg TSP ha^{-1})

Figure 16. Effect of phosphorus on stover yield (t ha^{-1}) of soybean (SE = NS)

4.3.2.2. Effect of K fertilizer application

Stover yield of soybean varied significantly with different level of K application (Figure 17 and Appendix XI). The maximum (3.72 t ha^{-1}) stover yield was recorded from K_2 whereas, the minimum (2.58 t ha^{-1}) was obtained from K_0 which was statistically at par with K_3 (2.82 t ha^{-1}). Similar findings were observed by Jahan *et al.* (2009).



(K_0= 0 kg MoP ha^{-1}, K_1= 60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1}, K_3= 180 kg MoP ha^{-1})

Figure 17. Effect of potassium on stover yield (t ha^{-1}) of soybean (SE = 0.17)

4.3.2.3. Combined effect of P and K fertilizer application

Combined effect of P and K application had significant effect on stover yield of soybean (Table 10). The highest stover yield (4.02 t ha^{-1}) was recorded from P_1K_2 which was statistically similar with P_2K_2 (4.01 t ha^{-1}) whereas, the lowest (2.28 t ha^{-1}) was obtained from P_1K_0 which was statistically at par with P_1K_3 (2.41 t ha^{-1}) and P_2K_0 (2.62 t ha^{-1}).

Table 10. Combined effect of P and K on yield and harvest index of soybean

Treatment combinations	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
P_0K_0	1.78 e	2.64 bc	4.41 e	40.42 ab
P_0K_1	2.14 c-e	2.92 a-c	5.06 de	42.19 ab
P_0K_2	2.45 b-e	3.28 a-c	5.73 b-e	43.05 ab
P_0K_3	1.88 e	2.93 a-c	4.81 de	38.09 b
P_1K_0	2.18 c-e	2.28 c	4.46 e	48.87 ab
P_1K_1	2.74 a-e	3.16 a-c	5.90 b-e	46.57 ab
P_1K_2	3.09 a-d	4.02 a	7.12 ab	43.45 ab
P_1K_3	2.33 c-e	2.41 c	4.74 de	48.50 ab
P_2K_0	2.49 b-e	2.62 bc	5.11de	48.67 ab
P_2K_1	3.13 a-c	3.39 a-c	6.52 a-d	47.90 ab
P_2K_2	3.67 a	4.01a	7.69 a	48.20 ab
P_2K_3	2.72 a-e	2.82 bc	5.54 b-e	49.38 a
P_3K_0	1.97 e	2.78 bc	4.75 de	40.31 ab
P_3K_1	2.48 b-e	3.07 a-c	5.55 b-e	44.84 ab
P_3K_2	3.42 ab	3.56 ab	6.98 a-c	48.79 ab
P_3K_3	2.08 de	3.13 a-c	5.21 c-e	39.58 ab
SE	0.31	0.33	0.54	3.13
CV (%)	20.83	18.76	16.73	12.09

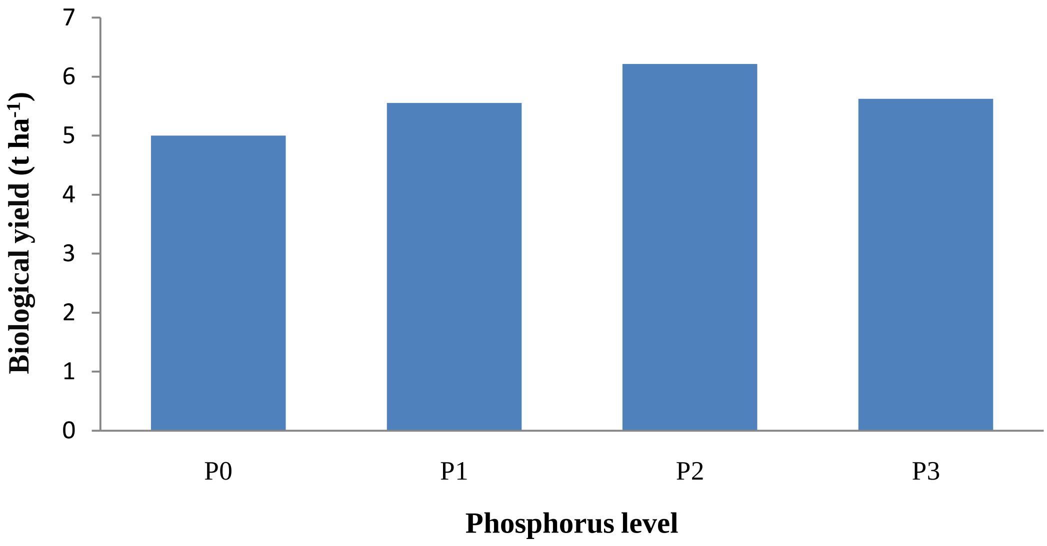
In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability

(P_0=No TSP, P_1=100 kg TSP ha^{-1}, P_2=175 kg TSP ha^{-1}, P_3=250 kg TSP ha^{-1}, K_0=No MoP, K_1=60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1} and K_3=180 kg MoP ha^{-1})

4.3.3. Biological yield (t ha^{-1})

4.3.3.1. Effect of P fertilizer application

Biological yield of soybean varied significantly with different level of P application (Figure 18 and Appendix XI).The maximum biological yield of soybean (6.22 t ha^{-1}) was recorded from P_2 which was statistically similar with P_3 (5.62 t ha^{-1}) and P_1 (5.55 t ha^{-1}) and the minimum (5.00 t ha^{-1}) was recorded where, no phosphorus was applied..

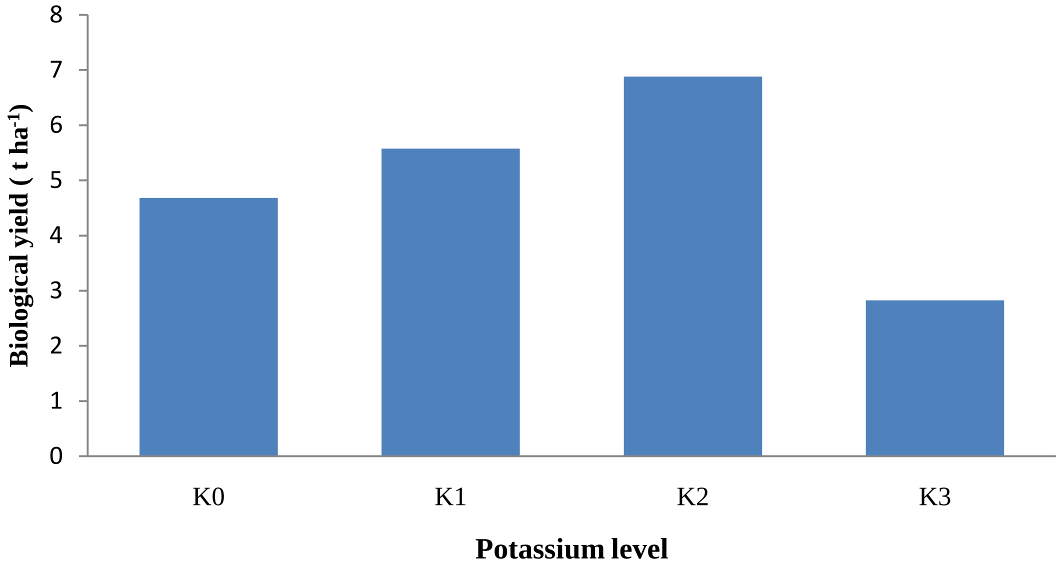


(P_0= 0 kg TSP ha^{-1}, P_1= 100 kg TSP ha^{-1}, P_2= 175 kg TSP ha^{-1}, P_3= 250 kg TSP ha^{-1})

Figure 18. Effect of phosphorus on biological yield (t ha^{-1}) of soybean (SE= 0.27)

4.3.3.2. Effect of K fertilizer application

Biological yield of soybean varied significantly with different level of K application (Figure 19 and Appendix XI).The maximum biological yield (6.88 t ha^{-1}) was recorded in K_2 where the level of potassium (120 kg ha^{-1}) and the lowest (4.68 t ha^{-1}) was, however, found in case of control treatment which was statistically similar with K_3 (5.08 t ha^{-1}). Generally biological yield increased with increasing rate of fertilizer application. These results are similar to Munir and McNeilly (1987) who reported that increasing rates of K increased the biological yield.



(K_0= 0 kg MoP ha^{-1}, K_1= 60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1}, K_3= 180 kg MoP ha^{-1})

Figure 19. Effect of potassium on biological yield (t ha^{-1}) of soybean (SE= 0.27)

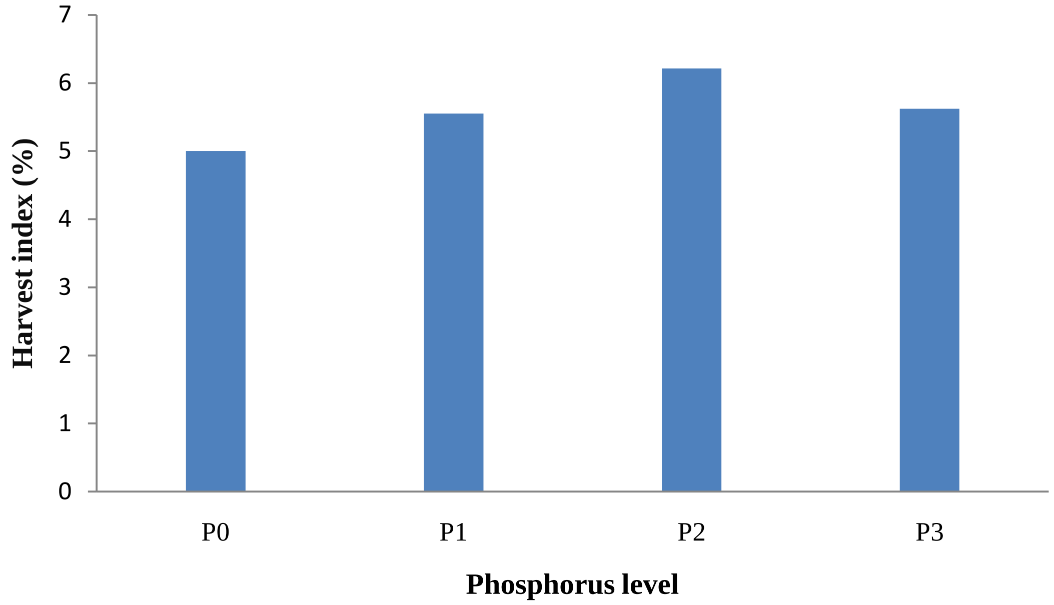
4.3.3.3. Combined effect of P and K fertilizer application

Combined effect of P and K application had significant effect on biological yield of soybean (Table 10). The highest biological yield (7.69 t ha^{-1}) was recorded from P_2K_2 which was statistically similar with P_1K_2 (7.12 t ha^{-1}) and P_3K_2 (6.98 t ha^{-1}) while, the lowest (4.41 t ha^{-1}) was found from P_0K_0 which was statistically at par with P_1K_0 (4.46 t ha^{-1}) and P_1K_3 (4.74 t ha^{-1}).

4.3.4. Harvest index (%)

4.3.4.1. Effect of P fertilizer application

Harvest index of soybean varied significantly with different level of P application (Figure 20 and Appendix XI).The maximum HI of soybean (48.54 %) was recorded from P_2 which was statistically similar with P_1 (46.85 %) and the minimum (40.94 %) was found from P_0 which was statistically at par with P_3 (43.38 %). The present result consistent with the findings of Malik *et al.* (2006) who found that HI varied significantly due to different phosphorus level but Mabapa *et al.* (2010) reported that P did not affect the harvest index.

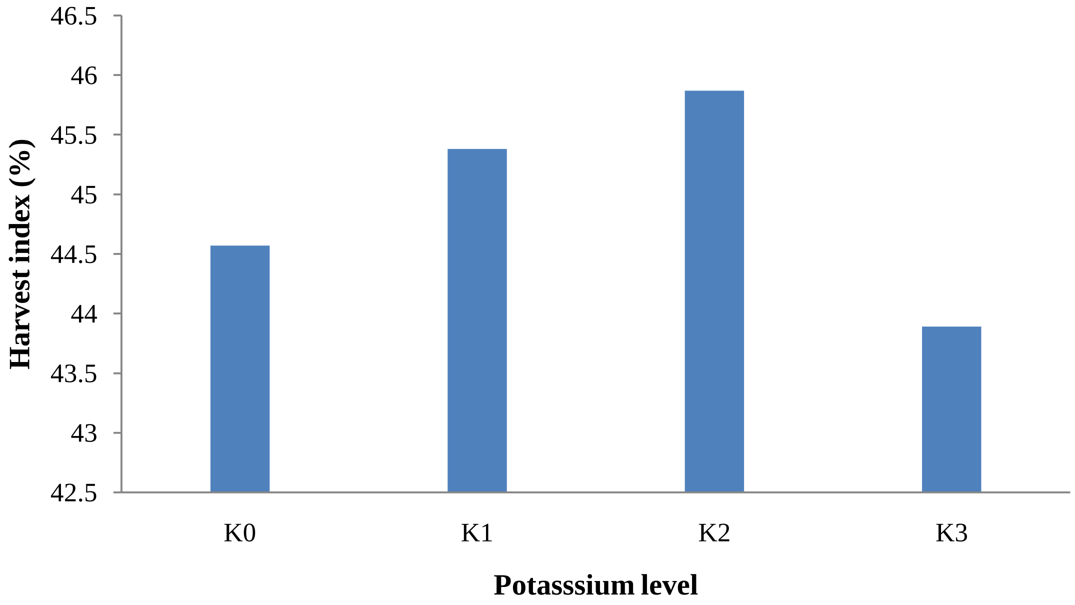


(P_0= 0 kg TSP ha^{-1}, P_1= 100 kg TSP ha^{-1}, P_2= 175 kg TSP ha^{-1}, P_3= 250 kg TSP ha^{-1})

Figure 20. Effect of phosphorus on harvest index (%) of soybean (SE= 1.57)

4.3.4.2. Effect of K fertilizer application

Harvest index of soybean had non-significant with different level of K application (Figure 21 and Appendix XI).The maximum HI values (45.87 %) were recorded in K_2 treatment (120 kg MoP ha^{-1}) and thereafter the increasing level of K resulted in decreased HI. Xiang *et al.* (2012) observed that the highest harvest index (42.8 %) was produced by soybean at the rate of 112.5 kg K ha^{-1} and the lowest (40.0 %) was recorded in control treatment. These results are consistent with the findings of Khan *et al*. (2004) who found that HI increase within a certain level and then decreased.



(K_0= 0 kg MoP ha^{-1}, K_1= 60 kg MoP ha^{-1}, K_2= 120 kg MoP ha^{-1}, K_3= 180 kg MoP ha^{-1})

Figure 21. Effect of potassium on harvest index (%) of soybean (SE=NS)

4.3.4.3. Combined effect of P and K fertilizer application

Combined effect of P and K application had significant effect on harvest index of soybean (Table 10). The maximum value of harvest index (49.38 %) was recorded from P_2K_3 which was statistically at par with P_1K_0 (48.87 %) and P_3K_2 (48.79 %) while, the lowest (38.09 %) was observed from P_0K_3.

Chapter 5

Summary and conclusion

SUMMARY AND CONCLUSION

The field experiment was conducted at the Agronomy field of Sher-e-Bangla Agricultural University (SAU), Dhaka, under the Modhupur Tract (AEZ-28) during the period from December, 2013 to April, 2014 to evaluate the effect of phosphorus and potassium on the performance of soybean (BARI soybean-6). The experiment was layout in a split plot design with three replications. The experiment was comprised (a) four levels of phosphorus viz. 0 kg TSP ha^{-1} (P_0), 100 kg TSP ha^{-1} (P_1) , 175 kg TSP ha^{-1} (P_2) and 250 kg TSP ha^{-1} (P_3) and (b) four levels of potassium viz. 0 kg MoP ha^{-1} (K_0), 60 kg MoP ha^{-1} (K_1), 120 kg MoP ha^{-1} (K_2)and 180 kg MoP ha^{-1} (K_3). The treatment combinations were randomly distributed in each block. The size of each plot was 2.0 m x 2.0 m (4 m^2) and total numbers of plots were 48. There were 16 treatment combinations. The spacing between blocks and units were 0.75 m and 0.50 m respectively. A dose of 60 kg urea ha^{-1} and 115 kg gypsum ha^{-1} was applied. The seed were sown in 30 cm apart lines with 5 cm hill spacing on 28 December, 2013. Phosphorus rate treatments were placed at the main plots and potassium rate treatments were placed at the sub plots.

The data on crop growth characters like plant height (cm), number of branches plant^{-1}, leaf area index, number of nodules plant^{-1}, fresh weight (g plant^{-1}) and dry weight (g plant^{-1}) were recorded at different growth stages. Yield contributing characters like, number of filled pods plant^{-1}, pod length (cm), number of seeds pod^{-1}, 1000-seed weight, seed yield, stover yield, biological yield and harvest index were recorded after harvest. Data were analyzed using MSTAT-C computerized package program. The mean differences among the treatments were compared by Duncan's Multiple Range Test (DMRT) at 5% level of significance.

All studied crop characters were significantly influenced by different levels of phosphorus except plant height and number of branches plant^{-1}, fresh weight, dry weight, and stover yield. The highest number of nodules plant^{-1}, number of filled pods plant^{-1}, length of pod, number of seeds pod^{-1}, seed yield, biological yield and harvest index were obtained when phosphorus used @ 175 kg TSP ha^{-1} and the lowest from 0 kg TSP ha^{-1} or control treatment. On the other hand, 250 kg TSP ha^{-1} showed maximum leaf area index which were identical with 175 kg TSP ha^{-1}.

The level of potassium also significantly influenced all the characters except plant height (30 DAS) and harvest index. Potassium used @ 120 kg MoP ha^{-1} produced the highest plant height (45, 60 and 75 DAS), number of branches plant^{-1}, leaf area index (30, 45 and 60 DAS), number of nodules plant^{-1} (60 and 90 DAS), fresh weight, dry weight, filled pods plant^{-1}, number of seeds pod^{-1}, seed yield, biological yield and harvest index whereas, the lowest from control treatment or where no potassium was applied. On the other hand, 60 kg MoP ha^{-1} produced highest plant height at 90 and 105 DAS. The maximum leaf area index produced when potassium used @180 kg MoP ha^{-1} at 75, 90 and 105 DAS. The highest number of nodules was produced at 30 DAS when field was treated with 180 kg MoP ha^{-1} which was identical with 120 kg MoP ha^{-1}. The maximum dry weight was produced at 90 DAS when potassium used @ 180 kg MoP ha^{-1} which all were identical with 120 kg MoP ha^{-1}.

The combined effect of phosphorus and potassium also significantly influenced growth, yield and yield contributing characters but the combined effect of phosphorus and potassium did not show any significant effect on plant height at (30 and 60 DAS), dry weight at 30 DAS and length of pod. The tallest plant at 75 DAS was obtained from the combination of 175 kg TSP ha^{-1} + 120 kg MoP ha^{-1} and whereas, the shortest plant recorded from 175 kg TSP ha^{-1} + 0 kg MoP ha^{-1} combination. The tallest plant at 90 and 105 DAS was obtained from the combination of 175 kg TSP ha^{-1} + 60 kg MoP ha^{-1} while, the smallest plant observed from 175 kg TSP ha^{-1} + 180 kg MoP ha^{-1} treatment combination. The maximum number of branches plant^{-1} at 45 and 90 DAS was observed when P and K simultaneously used @ 100 kg TSP ha^{-1} + 120 kg MoP ha^{-1} but at 60 and 75 DAS maximum number of branches was recorded from 250 kg TSP ha^{-1} +

120 kg MoP ha^{-1} treatments combination while, in every cases the lowest number of branches obtained from control treatment combination. The maximum leaf area index at 30 and 75 DAS was recorded from 250 kg TSP ha^{-1} + 180 kg MoP ha^{-1} treatment combination, 175 kg TSP ha^{-1} + 120 kg MoP ha^{-1} at 45 DAS, 175 kg TSP ha^{-1} + 180 kg MoP ha^{-1} at 60 and 90 DAS and 105 DAS maximum leaf area obtained when phosphorus and potassium used @ 250 kg TSP ha^{-1} + 120 kg MoP ha^{-1} treatment combination and in every case the lowest leaf area recorded where no P or K was applied. The maximum number of nodules plant^{-1} at 90 DAS was recorded from 175 kg TSP ha^{-1} + 180 kg MoP ha^{-1} treatment combination and the minimum number of nodules was obtained from the control treatments combination at 30 and 60 DAS but at 60 and 90 DAS the maximum number of nodules plant^{-1} was observed from 100 kg TSP ha^{-1} + 120 kg MoP ha^{-1} treatment combination whereas, the lowest obtained from the combination of 100 kg TSP ha^{-1} + 0 kg MoP ha^{-1} at 90 DAS. The maximum fresh weight obtained from the combination of 250 kg TSP ha^{-1} + 120 kg MOP ha^{-1} at 30 DAS, 175 kg TSP ha^{-1} + 120 kg MoP ha^{-1} at 60 DAS and 90 DAS while, the minimum fresh weight recorded from the combination of 0 kg TSP ha^{-1} + 0 kg MoP ha^{-1} at 30 and 60 DAS and 250 kg TSP ha^{-1} + 0 kg MoP ha^{-1} at 90 DAS. The maximum dry weight recorded from 175 kg TSP ha^{-1} + 120 kg MoP ha^{-1} treatment combination at 60 DAS while, the minimum obtained from the combination of 175 kg TSP ha^{-1} + 0 kg MoP ha^{-1} but at 90 DAS, the highest dry weight recorded from 0 kg TSP ha^{-1} + 120 kg MoP ha^{-1} whereas, the lowest was obtained when P and K used @ 100 kg TSP ha^{-1} + 0 kg MoP ha^{-1}. The highest filled pods plant^{-1} and number of seeds pod^{-1} was obtained from the combination of 175 kg TSP ha^{-1} + 120 kg MoP ha^{-1} while, the lowest recorded from control treatments combination. The maximum seed yield and biological yield was recorded from 175 kg TSP ha^{-1} + 120 kg MoP ha^{-1} combination while, the lowest obtained where no P or K was applied but the highest stover yield and harvest index was observed from the combination of 100 kg TSP ha^{-1} + 120 kg MoP ha^{-1} and 175 kg TSP ha^{-1} + 180 kg MoP ha^{-1}

whereas, the lowest estimated at the combination of 100 kg TSP ha^{-1} + 0 kg MoP ha^{-1} and 0 kg TSP ha^{-1} + 180 kg MoP ha^{-1}.

From the above discussion it is observed that in most of the cases phosphetic fertilizer showed the significant effect on growth, yield and yield attributes of soybean and application of 175 kg TSP ha^{-1} contributed better performances in terms of growth and yield of soybean. The effect of potassic fertlizer also showed significant effect on growth, yield and yield attributes of soybean in many cases and application 120 kg MoP ha^{-1} produced the highest growth and yield of soybean. The combination effect of phosphetic and potassic fertilizer also showed positive effects on growth and yield contributing characters and the combination of 175 kg TSP ha^{-1} + 120 kg MoP ha^{-1} gave maximum results on growth and yield attributes, and yield of soybean.

From the above discussions it may be concluded that application of phosphetic and potasssic fertilizer influenced soybean growth and yield as well as production. Although the effects of P and K played important role on growth and yield of soybean but excess amount gave negative impacts on soybean cultivation. Therefore, judicious combine application of these two vital elements through TSP and MoP fertilizers respectively is needed and based of this research results it could be suggested that application of 175 kg TSP ha^{-1} and 120 kg MoP ha^{-1} to be a promising practice for soybean cultivation in Bangaldesh. However, to reach a specific conclusion and recommendation, more research work on the application of phosphetic and potassic fertilizer in soybean cultivation should be done over different Agro-ecological zones.

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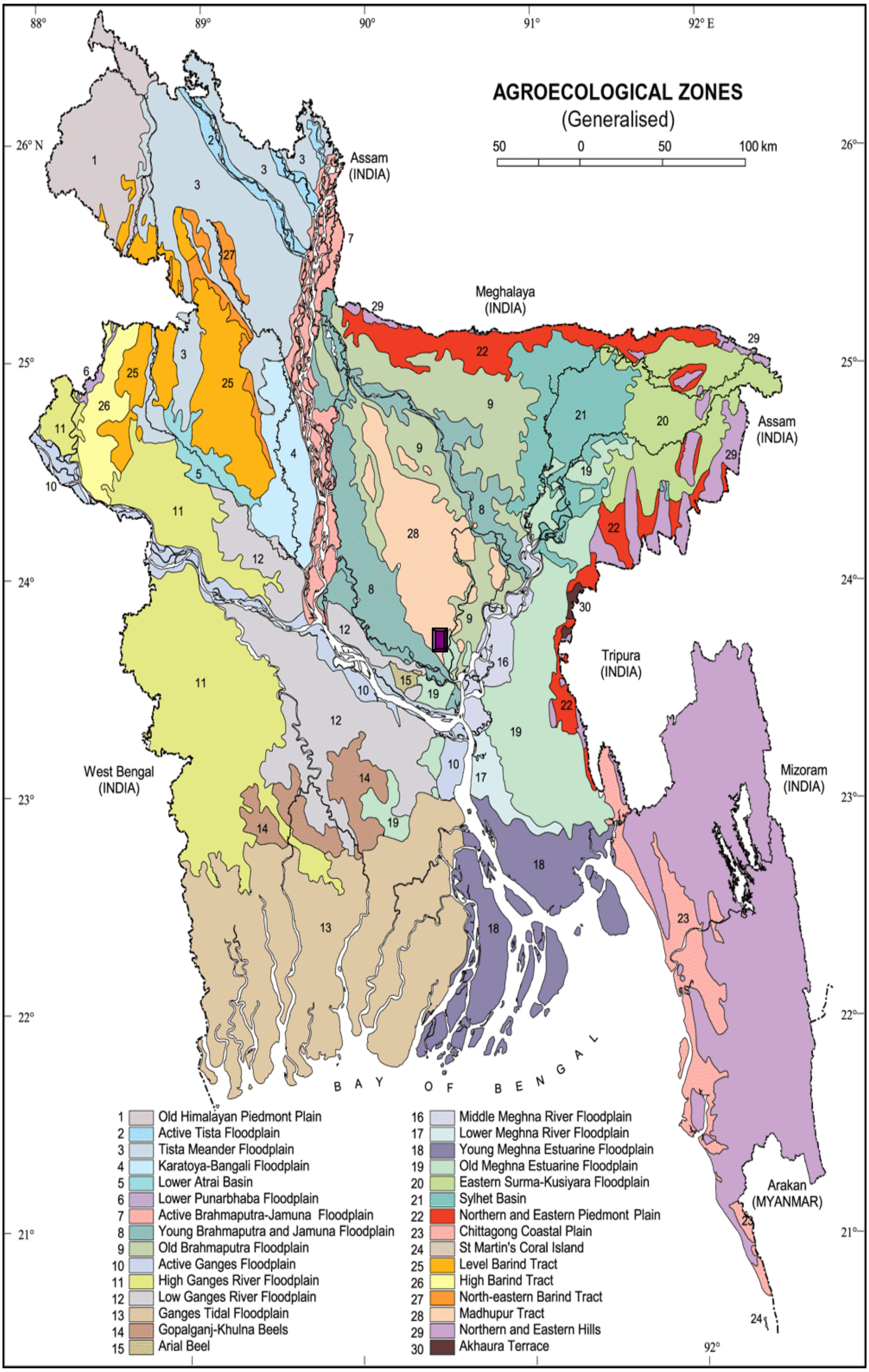
Appendices

APPENDICES



Appendix I. Map showing the experimental site under study

Appendix II. Weather data, 2013-2014, Dhaka

Month	Average RH (%)	Average Temperature (ºC)		Total Rainfall (mm)
		Min.	Max.	
December	54.30	5.21	25.36	0.21
January	64.02	15.46	21.17	0.00
February	53.07	19.12	24.30	2.34
March	48.66	22.37	29.78	0.12
April	51.02	22.85	33.82	2.19

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1207.

Appendix III. Physicochemical properties of the initial soil

Characteristics	Value
Particle size analysis	
% Sand	26
% Silt	45
% Clay	29
Textural class	Silty-clay
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/ 100 g soil)	0.10
Available S (ppm)	45

Source: Soil Resources Development Institute (SRDI), Dhaka-1207

Appendix IV. Mean square values for plant height of soybean at different days after sowing

Sources of variation	DF	Mean square values					
		30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	105 DAS
Replication	2	0.963	9.642	25.379	49.012	37.816	39.108
Phosphorous (P)	3	1.368^{NS}	10.093 ^{NS}	12.626 ^{NS}	12.553 ^{NS}	22.663 ^{NS}	29.077 ^{NS}
Error (a)	6	1.560	1.874	5.705	23.311	26.497	36.798
Potassium (K)	3	0.903 ^{NS}	10.823*	39.017*	104.775*	150.024*	128.686*
P x K	9	1.001 ^{NS}	1.091*	5.077 ^{NS}	11.149*	39.216*	35.662*
Error (b)	24	1.401	5.219	20.767	32.024	32.743	18.972

**: Significant at 0.01 level of probability *: Significant at 0.05 level of probability NS: Non-significant

Appendix V. Mean square values for number of branches plant^{-1} of soybean at different days after sowing

Sources of variation	DF	Mean square values				
		45 DAS	60DAS	75 DAS	90 DAS	At harvest
Replication	2	0.065	0.271	0.016	0.760	1.092
Phosphorus (P)	3	0.077 ^{NS}	2.045**	0.503 ^{NS}	0.828 ^{NS}	1.147^{NS}
Error (a)	6	0.022	0.183	0.332	0.375	0.309
Potassium (K)	3	1.489**	11.290**	6.921**	3.726**	5.367*
P x K	9	0.046*	0.730**	0.210*	1.335*	0.515**
Error (b)	24	0.036	0.216	0.435	0.731	0.638

**: Significant at 0.01 level of probability *: Significant at 0.05 level of probability NS: Non-significant

Appendix VI. Means square values for leaf area index of soybean at different days after sowing

Sources of variation	DF	Mean square values					
		30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	105 DAS
Replication	2	0.039	0.036	0.057	0.051	0.143	0.123
Phosphorous (P)	3	0.302*	2.189*	1.748**	1.095**	2.009**	1.79*
Error (a)	6	0.088	0.257	0.056	0.094	0.044	0.49
Potassium (K)	3	0.884**	1.007**	0.866**	1.361**	1.919**	1.327*
P x K	9	0.047*	0.069*	0.057*	0.080*	0.146*	0.93*
Error (b)	24	0.080	0.086	0.123	0.098	0.065	0.093

**: Significant at 0.01 level of probability *: Significant at 0.05 level of probability

Appendix VII. Means square values for number of nodules plant^{-1} of soybean at different days after sowing

Sources of variation	DF	Means square values		
		30 DAS	60 DAS	90 DAS
Replication	2	26.212	245.822	0.506
Phosphorous (P)	3	8.173*	34.171*	3.667*
Error (a)	6	3.164	13.384	1.498
Potassium (K)	3	9.935**	78.942**	26.132
P x K	9	0.949*	4.554*	2.086*
Error (b)	24	0.530	8.385	0.761

**: Significant at 0.01 level of probability *: Significant at 0.05 level of probability

Appendix VIII. Mean square values for fresh weight plant^{-1} of soybean at different days after sowing

Sources of variation	DF	Mean square values		
		30 DAS	60 DAS	90 DAS
Replication	2	1.946	192.023	2029.678
Phosphorous (P)	3	0.552 ^{NS}	31.521 ^{NS}	643.478 ^{NS}
Error (a)	6	0.239	145.100	684.191
Potassium (K)	3	2.325*	255.604*	8081.734**
P x K	9	0.305*	24.722*	1724.659*
Error (b)	24	0.658	61.385	686.647

**: Significant at 0.01 level of probability *: Significant at 0.05 level of probability NS: Non-significant

Appendix IX. Mean square values for total dry weight plant^{-1} of soybean at different days after sowing

Sources of variation	DF	Mean square values		
		30 DAS	60 DAS	90 DAS
Replication	2	0.062	7.085	33.036
Phosphorous (P)	3	0.019 ^{NS}	1.754 ^{NS}	87.490 ^{NS}
Error (a)	6	0.019	3.263	137.017
Potassium (K)	3	0.078*	15.742*	1032.340**
P x K	9	0.002*	1.633*	195.663*
Error (b)	24	0.024	3.947	96.820

**: Significant at 0.01 level of probability *: Significant at 0.05 level of probability NS: Non-significant

Appendix X. Means square values for number pods plant^{-1}, length of pod, number of seeds pod^{-1} and 1000-seed weight of soybean

Sources of variation	DF	Mean square values			
		Filled pods plant^{-1}	Length of pod	Number of seeds pod^{-1}	1000-seed weight
Replication	2	417.540	0.243	0.215	7.826
Phosphorous (P)	3	191.829*	0.005^{NS}	0.058*	50.420**
Error (a)	6	199.830	0.016	0.082	4.256
Potassium (K)	3	804.160*	0.036*	0.124*	56.902**
P x K	9	65.289*	0.004^{NS}	0.008*	4.414*
Error (b)	24	179.504	0.018	0.062	4.032

**: Significant at 0.01 level of probability *: Significant at 0.05 level of probability NS: Non-significant

Appendix XI. Mean square values for seed yield, stover yield, biological yield and harvest index of soybean

Sources of variation	DF	Mean square values			
		Seed yield	Stover yield	Biological yield	Harvest index
Replication	2	1.048	1.284	3.872	50.141
Phosphorous (P)	3	0.765*	0.905^{NS}	2.834*	140.184^{NS}
Error (a)	6	0.465	0.602	1.974	21.217
Potassium (K)	3	0.650**	2.372**	9.999**	9.207*
P x K	9	0.080*	0.333*	0.661*	26.729*
Error (b)	24	0.279	0.385	1.147	29.490

**: Significant at 0.01 level of probability *: Significant at 0.05 level of probability NS: Non-significant

Plate 1: Field view of the experimental plot

Plate 2: Pod bearing stage of soybean