PHOSPHORUS ADSORPTION – DESORPTION AS INFLUENCED BY VARIOUS LEVELS OF PHOSPHORUS UNDER SOYBEAN GROWN IN VERTISOLS

THESIS

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Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
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By

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DECLARATION OF STUDENT

I hereby declare that, the experimental work and its interpretation of the thesis entitled **"PHOSPHORUS ADSORPTION - DESORPTION AS INFLUENCED BY VARIOUS LEVELS OF PHOSPHORUS UNDER SOYBEAN GROWN IN VERTISOLS"** or part thereof has neither been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis / publication of any University or scientific organization. The source of materials used and all assistance received during the course of investigation have been duly acknowledged.

Place: Akola (**TEMBHURNE SUSHIL SURYABHAN)**

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CERTIFICATE

This is to certify that thesis entitled **"PHOSPHORUS ADSORPTION - DESORPTION AS INFLUENCED BY VARIOUS LEVELS OF PHOSPHORUS UNDER SOYBEAN GROWN IN VERTISOLS"** submitted in partial fulfillment of the requirements for the degree of **"Master of Science in Agriculture (Soil Science and Agricultural Chemistry)"** of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, is a record of bonafide research work carried out by **TEMBHURNE SUSHIL SURYABHAN** under my guidance and supervision.

The subject of the thesis has been approved by the Student's Advisory Committee.

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(D) Abbreviations

%	:	Per Cent
/	:	Per
@	:	At the rate
µg	:	Microgram
^0C	:	Degree Celsius
Al	:	Aluminium
Ca	:	Calcium
$CaCO_3$	:	Calcium Carbonate
CD	:	Critical Difference
cm	:	Centimetre
cm hr^{-1}	:	Centi metre per hour
cm^3		Cubic centimeter
Conc.		Concentration
Cu	:	Copper
DAP	:	Diammonium phosphate
DAS		Days After Sowing
dS m^{-1}	:	Deci Siemens per meter
EC	:	Electrical Conductivity
Fe	:	Iron
Fig.	:	Figure
FYM	:	Farm Yard Manure
g ha^{-1}	:	Grams per hectare
g kg^{-1}	:	Grams per kilogram
g^{-1}	:	Per gram
$H_2PO_4^-$	:	Dihydrogenphosphate
ha^{-1}	:	Per hectare
HPO_4^{2-}	:	Hydrogenphosphate
hr^{-1}	:	Per hour

K	:	Potassium
Kg	:	Kilogram
kg ha^{-1}	:	Kilograms per hectare
kPa	:	Kilo Pascal
m^2	:	Square meters
me L^{-1}	:	Milli equivalant per liter
mg kg^{-1}	:	Miligram per kilogram
Mg m^{-3}	:	Mega grams per cubic meter
mg $plant^{-1}$		Miligram per plant
Mg^{2+}	:	Magnesium
mm	:	Milimeter
Mn	:	Manganese
MOP	:	Muriate of Potash
MW	:	Meteorological Week
MWD	:	Mean Weight Diameter
N	:	Nitrogen
N.S.	:	Non Significant
Na^+	:	Sodium
O.C.	:	Organic Carbon
P	:	Phosphorus
ppm	:	parts per million
q ha^{-1}	:	Quintal per hectare
RF	:	Rainfall
RH	:	Relative humidity
SE(m)	:	Standard Error of Mean
t ha^{-1}	:	Tonne per hectare
TSP	:	Triple Super Phosphate
yr^{-1}	:	Per year

(E) THESIS ABSTRACT

a.	Title of the thesis	:	**PHOSPHORUS ADSORPTION-DESORPTION AS INFLUENCED BY VARIOUS LEVELS OF PHOSPHORUS UNDER SOYBEAN GROWN IN VERTISOLS**
b.	Full name of student	:	**TEMBHURNE SUSHIL SURYABHAN**
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ABSTRACT

The present investigation entitled, "Phosphorus adsorption-desorption as influenced by various levels of phosphorus under soybean grown in Vertisols" was undertaken during 2019-20 at Research Farm, Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra. The soil of the experimental site was Vertisols which was moderately alkaline in reaction, low in available nitrogen, low in available phosphorus and high in available potassium. The study was framed with an object to assess the effect of various levels of phosphorus on adsorption-desorption of phosphorus and on yield and uptake of nutrients by soybean. The experiment was laid out in Randomized Block Design with five treatments randomized in four replications. The treatments comprised of various levels of phosphorus viz. 0, 45, 60, 75, and 90 kg ha^{-1} along with recommended dose of nitrogen and potassium @30 kg each excluding control treatment.

The results indicate very less effect of fertilization on P adsorption and desorption. The buffering capacity with respect to different treatments was non-significant and therefore it was found that the respective soil has low phosphate adsorption capacity. The various levels of phosphorus have significant effect on inorganic forms of phosphorus i.e. Al-P, Fe-P, Ca-P. The high values of Ca-P than Fe-P and Al-P might be due to the alkaline pH of soil. Grain, straw yield, total uptake of nitrogen, phosphorus and potassium were increased significantly in soybean with increasing levels of phosphorus. The effect of various levels of phosphorus did not have significant influence on nitrogen and potassium concentration in soybean. However, the phosphorus content significantly increased with the increasing levels of phosphorus.

The chemical properties and available nutrient status of soil was not influenced by various levels of phosphorus except available phosphorus, which was significantly influenced with increasing levels of phosphorus along the recommended dose of nitrogen and potassium.

The number and dry weight of nodules as well as root length and volume were influenced significantly with incremental levels of phosphorus. Hence, based on the present investigation it has been observed that the increasing levels of phosphorus has vital role in grain and straw yield of soybean, while it has little contribution in adsorption and desorption of phosphorus in soil.

CHAPTER I

INTRODUCTION

1.1 Background information

Soybean (*Glycine max* L. Merrill) is the world's most important seed legume, which contributes to 25% of the global edible oil. The cultivation and use of soybean could be traced back to the beginning of China's agricultural age. Chinese medical compilations, dating back 6,000 years, mention its utilization for human consumption. To the populace of China, Japan, Korea, Manchuria, Philippines and Indonesia, for centuries, soybean has meant to be meat, milk, cheese, bread, and oil. This could well be the reason, why in these countries, it has earned epithets like ''Cow of the field'' or ''Gold from soil''. Owing to its amino acids composition, the protein of soybean is called a complete protein. Its nutrition value in heart disease and diabetes is well known. It is necessary to mention that, Chinese infants using soybean milk instead of cow's milk are practically free from rickets. Today, USA, Brazil and Argentina are the ''Big-3'' producers of soybean in the world. Versatility of soybean was recognized within the West Country recently.

In India, soybean was introduced from China in tenth century AD through the Himalayan routes and also brought in via Burma (now Myanmar) by traders from Indonesia. As a result, soybean has been traditionally grown on a small scale in Himachal Pradesh, the Kumaon Hills of Uttaranchal, eastern Bengal, the Khasi Hills, Manipur, the Naga Hills and parts of central India covering Madhya Pradesh. It has also been reported that the Indian continent is the secondary centre for domestication of the crop after China. At present, India ranks fifth in the area and production in the world after USA, Brazil, Argentina and China (Source statista, 2018). The contribution of India within the world soybean area is 10%, but the contribution to total world soybean grain is merely 4 % indicating the poor levels of productivity in India (1.1 t/ha) as compared to other courtiers (world average 2.2 t/ha) (Agarwal *et al*. 2013).

Soybean has become the crucial oilseed crop in India within very short period covering approximately 10 million ha area under its cultivation. India is divided into five agro-climatic zones for soybean cultivation viz., northern hill zone, northern plain zone, north eastern zone, central zone and southern zone. The specific varieties released for every zone depending on agro-climatic conditions. The major soybean growing states are Madhya Pradesh, Maharashtra, Rajasthan, Karnataka, Andhra Pradesh and Chattisgarh. These states together contribute to about 98% of the total soybean production within the country. Due to rapid expansion, soybean has surpassed in area and production of rest of the oilseeds in 2006-07 (Agarwal *et al*. 2013). Soybean is now predominantly grown as rainfed crop in Vertisols and associated soils with an average crop season rainfall of 900 mm, which varies greatly across locations and years. Introduction of soybean in these areas has led to a shift in cropping system. This has resulted in an enhancement within the cropping intensity and resultant increase within the profitability per unit land area.

Introduction of soybean has helped in improving the socio-economic conditions of huge number of small and marginal farmers probably due to the fact that even under minimum agricultural inputs, management practices and climatic adversities, it fetches profitable returns to the farmers. In fact, despite aberrant weather conditions in recent past soybean is one of the most resilient crops for rainfed region.

Soybean performs well under balanced nutritional conditions. The application of nitrogen, phosphorus and potassium has vital significance in enhancing yield and quality of soybean. Especially, phosphorus has very vibrant role in soybean.

Phosphorus is essential to all forms of life and important for its contribution towards aiding the native soil fertility, especially under intensive agriculture. The economic challenges associated with increasing phosphorus fertilizer prices are driving the increased interest in improving phosphorus use efficiency. Moreover, transfer of soil phosphorus from cultivated land through erosion or runoff is a major cause of P-induced eutrophication in surface waters. This underlines the significance of phosphorus management in taking care of native supplies and crop demands under given cropping system. In order to develop judicious phosphorus management options, it is essential to critically analyse the scientific knowledge pertaining to different aspects governing the availability of native and applied phosphorus to the crops.

Phosphorus occurs in soil predominantly in inorganic form, although organic forms of phosphorus may also contribute substantially (20–80%) to the total P content. In Indian soils, inorganic P generally contributes 54–84% of total P, whereas the share of organic P varies from 16% to 46% in different states. In most cases, total P content of soil is poorly correlated with plant available P and thus not used as a measure of P fertility of soil. The total P in soil consists of inorganic P and organic P forms. The inorganic P constitutes a dominant part of total P, it being 30-95 per cent of total P in soil. Phosphorus bound to aluminium (Al-P), iron (Fe-P) and calcium (Ca-P) constitutes the major active form of inorganic P. The relatively less active are the occluded and reductant-soluble forms of P. All these forms exist in all soils but generally Al-P and Fe-P are more abundant in acid soils while Ca-P dominates in neutral-alkaline soils. Various forms of P are interrelated and contribute to the pool of plant available-P according to their physicochemical properties.

Soil phosphorus exists in four different pools on the basis of its accessibility and extractability such as: soil solution P; surface-adsorbed P; strongly-bonded or absorbed P; and very strongly–bonded or inaccessible or mineral or precipitated P. In the soil solution, P is immediately available for uptake to the plant roots. The second pool represents readily extractable P held on the surface of soil components. This pool is considered to be in equilibrium with P in the soil solution and can be transferred readily to the soil solution as the concentration of P in the latter is lowered due to P uptake by plant roots. Researchers in India also recognize the existence of different pools of P in the soil and their accessibility to crops.

Phosphorus retention by soils is an important parameter for understanding problems in soil fertility, as well as for determining the environmental fate of P. A better understanding of energetics of P sorption, based on kinetic studies, it may help to elucidate mechanisms of P adsorption–desorption in soils. In general, the Freundlich adsorption isotherm provides a better fit of the equilibrium phosphate sorption data in soils than does the Langmuir adsorption isotherm, especially, at relatively higher concentrations of the phosphate. The Tempkin equation is based on a model in which the affinity term decreases linearly with the amount of adsorption and is termed thermodynamically superior over the other two.

The phosphate sorption process may be regarded as a process of partition of P between the bulk soil solution phase and surface phase. Such partition process is characterized by a distribution coefficient (ΔK). By using the appropriate extrapolation technique, it is possible to refer to the resulting standard differential Gibbs energy change (ΔG) values, accompanying the adsorption process to the limit of the infinitely dilute solution of the adsorbate (e.g. phosphate) corresponding to the minimum surface coverage at equilibrium. This would minimize the electrostatic interactions of sorbed P with charged surfaces of soil or that between the sorbed P species themselves. The negative magnitude of the ΔG values would indicate the spontaneity of the given sorption process in the soils, while exhibiting significant correlations with the sorption parameters of different adsorption isotherms used to describe P-fixation by soils and soil components. Under such circumstances, the stability of P sorption reaction products in soils, relative to P in soil solution, seems to be contributed towards P-fixing characteristics of these soils. Such information may preferably be incorporated into crop management practices when planning for an appropriate P source, rate and timing of application for a soil, given its P sorption–desorption behaviour.

Thus, for a soil with high P sorption capacity and strong P-binding energy, coupled with a high P sorption rate and poor P desorption characteristics, it may settle for a less soluble P source that releases P in soil solution in smaller concentrations, spread over a longer period of time. This is expected to slow down the P fixation reactions in the given soil and maintain fertilizer P in plant-available form for a longer period.

Soils are known to vary widely in their capacity to supply phosphorus to plants. Only a small fraction of total P in soil is found in plant available form. Its bioavailability in the soil is governed by several factors like soil pH, texture, moisture, lime content, applied nutrients, etc. Besides these, the fact that the form in which phosphorus exists in the soil is also a factor which contributes the complication in the mode of its availability (Kothandaraman and Krishnamoorthy, 1979). The total P content in Indian soils ranges from 100-2000 mg kg^{-1}. Since the different forms of soil phosphorus have different solubility under different soils and environmental conditions; the availability in soil and the uptake of phosphorus by crops should largely depend upon the different factors prevailing in and through the soils. Thus, knowledge of the dynamics of P in soil is helpful in understanding the soil processes influencing the availability of P and its uptake by plant.

1.2 Importance and need of study

The unique chemical composition of soybean seed, which incorporates the amount of nutraceutical compounds like isoflavons, tocopherol and lecithin besides 20 % oil and 40 % protein, has made it one of the most valuable agronomic crop in the world.(Hellal and Magdi, 2013) The food derived from soybean generally provides the health benefits and is a cheaper source of high-quality protein. The crop has potential to eliminate protein malnutrition prevailing in poor sections of society within the country. The foreign exchange earned from export of soy meal is encouraging draining out of high quality protein from the country which poor sector of society needs at reasonable price. The utilization of soybean for food uses in India is meager and it needs work in terms of blending with other foods to make taste acceptable. The high-quality soybean protein should be included in daily diet of Indian masses to mitigate the widespread energy-protein malnutrition.

It is also called as ‘Gold of soil’ due to its various qualities such as ease in cultivation, less requirement of fertilizer and labour. It builds up the soil fertility by fixing atmospheric nitrogen through nodules.

Symbiotically soybean fixes nitrogen and leaves about 25% for succeeding crop. All these qualities have made it an ideal crop for rotation.

Availability of P is influenced by the quantity of P present in soils, the form in which P exist and P response vary not only with crop but also with soil type. Phosphorus sorption capacity is an important characteristic that affect the rate and plant response to phosphate fertilizer application.

The data available indicate that phosphate is weakly held in Vertisol and that it maintains concentrations which are adequate to prevent severe deficiencies in many crops as most field experiments have indicated the response of crop to added P in Vertisol. Responses to added P are uncertain and unpredictable and it has been attributed to the fixation of added P by Vertisols, because of their high clay content.

Phosphate adsorption desorption are the key processes governing the availability of P to crops. A greater data base especially for important benchmark and identified soil series of Vertisols in Maharashtra with the backup of agronomic results on P response of crops, will greatly assist in evolving a sound P management strategy for Vertisols in Maharashtra and hence the present investigation was planned.

1.3 Objectives

The study on "Phosphorus adsorption – desorption as influenced by various levels of phosphorus under soybean grown in Vertisols" was planned with the following objectives:

1. To assess the effect of various levels of phosphorus on adsorption – desorption of phosphorus.
2. To study the effect of various levels of phosphorus on yield and uptake of nutrients by soybean.

1.4 Scope and limitation

Phosphorus is a major nutrient, taken up by plant through diffusion as $H_2PO_4^-$ and HPO_4^{2-}. Phosphorus is important for plant functions and plays an important role in cell energy transfer, respiration and photosynthesis. Phosphate bonds are used for energy storage as adenosine triphosphate (ATP), which is the primary source of energy for biological processes and also serve as structural component of nucleic acids (DNA and RNA), enzymes, phosphor-proteins and phospholipids. Therefore, phosphorus deficiency can drastically affect plant development and metabolism, which can irreversibly reduce yield potential when occurring at early plant growth stages.

Soybean has been estimated to be taken up 81% of total P uptake during the growing season. Phosphorus is removed from the soil primarily through crop removal. For instance, the P source and soil properties such as pH or drainage can impact soil P availability to plants. Maximum P availability is generally observed between pH 6.5 and 7.0

Phosphorus cycling in soils is a complex phenomenon and depends on environmental factors including soil moisture and temperature. The amount of labile or available P to plants in solution is low and is influenced by soil, plants and micro-organisms. Labile P has to be constantly replenished to replace plant needs over the course of a plant's life so that P in solution is available to the plant at every growth stage. Contribution and bioavailability of organic P in soil solution is not completely understood. Further, mechanisms controlling rate of P exchange and availability is also not completely understood. Phosphorus is taken up as an inorganic anion ($H_2PO_4^-$ and HPO_4^{2-}) and therefore, organic P must be mineralized prior to plant uptake. Because P transport to the root is predominantly through diffusion, uptake can be decreased by soil drying or increased by practices that increase root length. Rate of diffusion is affected by temperature and moisture; therefore it is not the quantity of P applied that affects availability, but the rate at which P in solution can be replenished.

Adding inorganic P fertilizers to soil will likely cause an increase in the concentration of P in soil solution. Fertilizer recommendations will be higher for soils that have a fine texture, high clay content and high pH. Soil pH has a large influence on soil test P and that at high levels it can form calcium phosphates. After fertilization, more than

80% of the P may become immobile due to the soil pH and other soil physiological processes.

The cost of phosphate fertilizer production is expensive and very energy intensive. In addition, phosphate reserves are finite and have already reached critical levels. It is important to determine if the current nutrient recommendations are sound and up to date to prevent unnecessary additions. Another issue with P management is the land use practices on the land with surface applied P. Applying high levels of P to land that is tilled, sloped or has poor soil structure and has a tendency to runoff. The runoff may flow into streams, ponds, lakes and downstream. Nutrient runoff causes eutrophication and excessive algae growth, reducing oxygen for aquatic animals and destroying ecosystems.

1.5 Hypothesis

Soybean is more efficient in producing good yield at low soil phosphorus levels than other major agronomic crops. Phosphorus is the most critical nutrient limiting soybean production and is deficient in the majority of soybean cultivated tracts. The fertilization to the legumes is usually P-based, since it is highly essential for intensive N fixation. Thus, considering the role of phosphorus in energy transformation and enhancing root growth is important element to be added. The response of soybean to P fertilization depends on soil moisture status, as soil moisture stress may decrease the availability of applied P, resulting in poor biomass production and reduced P uptake. The need for P fertilization is usually more in acidic soils than in others due to higher P fixation. In general, all the sources of P are equally effective in soybean, except rock phosphate. Rock phosphate is a poor source of P in neutral to alkaline soils, but a reasonably good source for acidic soils.

Plants require phosphorus for growth throughout their life cycle, especially during the early stages of growth and development. In soybean, the demand for P is the greatest during pod and seed development where more than 60% of P ends up in the pods and seed. Its uptake and utilization by soybean is essential for ensuring proper nodule formation and improving yield and quality of the crop. Very high soil phosphate depressed seed protein and oil content, while yield would be low if available phosphorus is less than 30 $kgha^{-1}$. The most important phosphorus sources in arable soils are chemical fertilizers, though 75 to 90 percent of the phosphorus is fixed with iron, calcium and aluminium in soil.

Phosphorus is a relatively immobile, nevertheless, in the anion form it is able to leach downward through the soil profile during times of precipitation or irrigation. Because the soil available P will leach, there is concern that excess P moves through tile drainage systems and move into water sources and pollutes fresh water sources. Excessive fertilization increases the cost of production but cannot be assured about potential yield. Therefore, it is important for researchers, agronomists, scientists and producers to have references to long-term research in this area to monitor P availability over time and with different land management practices. Because management practices alter soil structure, organic matter, water infiltration, temperature, etc., it is important to recognize that management practices will affect P mobility and uptake by plants.

Doses of P fertilizer affect the dynamics of P in the soil. Increasing the dose of fertilizer was followed by a reduction in uptake of P by plants and increased the leaching and sorption by soil. In clayey soil, P-inorganic fertilization cannot increases the concentration and the P element lose through the soil with drainage water.

Therefore, considering the behaviour of phosphorus in black soils, the doses and its application need to be refined. The oilseeds are responding well to application of phosphorus, if the time and method of phosphorus application is proper. Similarly, the transformation of phosphorus in black soils is also major concern. Keeping this in view, the present study was planned to find out the phosphorus adsorption – desorption as influenced by various levels of phosphorus under soybean grown in vertisols.

CHAPTER II

REVIEW OF LITERATURE

It has been attempted to summarize a brief review of the work done in respect of the experiment entitled "Phosphorus adsorption – desorption as influenced by various levels of phosphorus under soybean grown in Vertisols" The literature pertaining to the present study has been briefly reviewed under the following heads in this chapter.

2.1 Effect of various levels of phosphorus on inorganic forms of phosphorus

2.2 Effect of various levels of phosphorus on adsorption desorption of phosphorus

2.3 Effect of various levels of phosphorus on yield

2.4 Effect of various levels of phosphorus on nutrient uptake

2.5 Effect of various levels of phosphorus on chemical properties of soil

2.6 Effect of various levels of phosphorus on nodulation and roots

2.1 Effect on inorganic forms of phosphorus

Chang and Jackson (1958) applied various procedures for fractionation of P in widely different soil and observed the forms of P related to soil pH, cation activities and solubility's product of various phosphorus compounds. The Ca-P, Al-P forms probably occurred before chemical weathering which was explained on the basis of higher activities of Calcium and Aluminium ions before soil weathering than that of iron ions.

Sharma and Biswas (1974) studied the role of different forms of phosphorus in the mechanism of soil aggregation in soils of Ranchi, Padegaon, Sabour and Delhi. They revealed that the transformation of added phosphates into Al-P, Fe-P, reductant soluble phosphorus (Red-P) and Ca-P brought about the improvement in soil aggregates to varying degree in the alluvial, black and red soil. Red-P and Ca-P had brought about the improvement in soil aggregates to varying degrees in all soils. The role played by Ca-P was almost significant in calcifer black soil of padegaon. Residual phosphorus did not appear to contribute the aggregate formation. Out of Red-P, Fe-P, Al-P Red-P and Fe-P increased invariably.

Talathi *et al.* (1975) studied the distribution of various forms of soil phosphorus in soils of North-West Rajasthan. They found the distribution of Ca-P, Al-P and Fe-P fraction in profiles indicated effective movement of soil P from sub soil. Organic Phosphorus was highest in surface layers and ratios of organic carbon and total N to organic Phosphorus were narrow indicating high Phosphorus mineralization in these soils.

Kothandarman and Krishnamoorthy (1979) studied thirty four surface soils representing the four major groups of Tamilnadu *viz.* Red, black, laterite and alluvial soils which were examined for different forms of soil inorganic phosphorus. They reported that total P, Inorganic P and P fractions *viz*. Al-P, Fe-P, red-P and occluded P dominates in laterite soils and Ca-P dominates in black and alluvial soils. Total P showed a close relationship with other forms of P indicating the existence of equilibrium between total P and its different forms in the soils. The amount of total P, Al-P and Fe-P were mainly contributed by the fine fraction of soils.

Sood and Minhas (1988) studied four profiles representing the sub-humid temperate highland zone of Himachal Pradesh. They reported that, the organic ‘P’ and total ‘P’ content varied from 86 to 423 and 498 to 2166 ppm, respectively. The organic ‘P’ constituted 11.7 to 31.3 per cent of the total P. Inositol P was the major fraction of organic P and which ranged from 20 to 244 ppm and constituted on an average 45.6 % of total organic P, nucleic acid and lipid P constituted 5 % of total organic P.

Patnayak and Mishra (1989) studied the total P content of twelve acid soils belonging to Alfisols, Inceptisols and Entisols of Orissa. They revealed that, Inorganic P increased on submergence. Reductant soluble P (Red-S-P) was dominant in all the soils except in Alfisols. Submergence decreased Red-P and Ca-P and increased the Al-P and Fe-P fraction.

Vishwanath and Doddamani (1991) studied the surface samples (0-15 cm) of Vertisols in Malaprabha command area of Karnataka and reported the decease in saloid-P, organic P and total P with depth. Distribution of Al-P, Fe-P, Reductant Soluble-P, occluded P and Ca-P did not follow a definite pattern and Ca-P was the dominant form of P i.e., 18.3% of the total P.

Sharma and Tripathi (1992) revealed that phosphorus fraction of the surface layer of some acid hill soils of north-west India were fairly rich in total P reserve (average 493 ppm). The mineral, organic and residual P on an average constituted about 49.6, 46.6 and 33.6 per cent of total P. Among soil properties only clay fraction significantly influenced the total P and Fe-P.

Dakhore (1993) studied the effect of 11 year sorghum-wheat cropping and fertilizer use on the inorganic form of P and P adsorption characteristics in Entisol. Ca-P was the predominant form of P which ranged from 44.2 to 46.7 per cent, followed by Al-P (13.0%) and Fe-P (4.0%) and Sal-P (1.5%) respectively. Under unmanured farming, the depletion of inorganic P forms as compared to its original level followed the order Sal-P > Al-P > Fe-P > Ca-P. There was progressive buildup of P in the form of active, organic and total-P with application of higher dose of phosphorus.

Dongale *et al.* (1993) studied forms of phosphorus and their distribution in light profiles of coastal region. They revealed that the inorganic and organic P contributed 52.2 to 99.4 and 0.6 to 47.8 per cent of total P ranging from 250 to 800 ppm, respectively. Phosphorus status was found to decrease with depth.

Kumar *et al.* (1999) observed that all forms of inorganic P fractions increased with increase in P levels. The increase was more in green manure amended soil than in the soil incubated without green manure. However, Al-P fractions consistently increased after 90 days of incubation whereas, Ca-P decreased at 90 days of incubation.

Tembhare and Kaushal (2000) noted that in Typic Haplustert soils of Jabalpur, inorganic P fraction at the inception of experiment were found to be in decreasing order as Ca-P, Fe-P, AI-P, saloid-P and occluded-P. The treatment in which optimal and super optimal NPK dose were applied, the inorganic P fractions increased over a period of 20 years, indicating the transformation of applied P into all the P fractions.

Pandian and Jothimani (2001) observed that application of recommended level of P at 60 kg P_2O_5 maintained significantly and the distribution of added P into different fractions was in order of Ca-P > Fe-P > AI-P. Higher Ca-P, Fe-P and AI-P as compared to other levels, the amount of inorganic P varied.

Mondal *et al.* (2002) reported that Ca-P was the dominant inorganic P fraction (35.3%) followed by Fe-P (24.7%), reductant soluble P (24%), Al-P (13.9%) and occluded P(47%) were present more or less in equal proportion to total P. Apparently, Olsen-P was found to be a better availability index as it showed higher significant relationship with different inorganic P fractions than Bray 1, but the latter had a higher correlation coefficient with P uptake by wheat.

Murthy *et al.* (2002) observed that applied phosphate transformed mostly into Ca-P followed by Fe-P, Al-P and carbonate sorbed-P fractions and in general increased with increasing rate of phosphorus application in all the pedons irrespective of their percentage. Besides these fractions occluded-P in pedons derived from grey shale, granodiorite and limestone showed improvement compared to their respective initial soil occluded-P fraction values. Amongst the pedons, maximum Ca-P fraction i.e. 370 mg kg^{-1} was observed in the A horizon of pedon derived from granodiorite parent material. Parent material apparently did not seen to have much influence in modifying the soils ability to differentially enrich the added phosphorus into different fractions.

Singh *et al.*(2003) observed that Ca-P, available, organic and total P are higher in younger vertisols of Taswaria and Taswaria sodic series, derived from calcic-genesis complex, whereas the Al-P, Fe-P and occluded P fractions maintained their higher concentration in the order vertisols of Patant and Aklera series, originating from basalt. However, the similar relation did not hold good in Chambal and Kota series, having higher smectite and higher Ca-P, available P, organic P and total P as compared to vertisol of Bhatewar series. They also indicated that Ca-P, available P, organic P, total P decreased while Al-P, Fe-P and occluded-P fraction showed opposite trends with crack volume.

Sihag *et al.* (2005) studied effect of chemical fertilizer and organic manures on the amount and distribution of phosphorus fractions in soil after two cycles of rice-wheat cropping system. The amount of P recovered in saloid-P, Al-P and Ca-P form increased significantly with the application of inorganic fertilizers and their combined use with organic materials over control. The highest amount of all the forms of P was recorded under farm yard manure. Average across treatments, saloid-P constituted about 2 per cent of the total P. The Al-P and Fe-P accounted for 8.4 and 12.1 per cent of the total P, respectively. The Ca-P accounted for nearly 44 per cent of the total P.

Verma *et al.* (2009) studied the effect of various forage crop sequences on different forms of soil phosphorus after completion of three cycles in an Inceptisol of Genetic and Plant Breeding farm of Narendra Deva University of Agriculture and Technology, Faizabad. The saloid P, Al-P, Fe-P and Ca-P increased in surface soil (0.15 m) over initial status under all crop sequences but effect in subsoil (0.15-0.30 m) was not evident. Organic P depleted in the surface soil under all crop rotations except in cow pea-berseem where a slight build up was observed. Various crop sequences did not reflect any changes in the organic phosphorus status of the subsoil. The Olsen-P concentration increased over initial value under cowpea-berseem followed by cowpea, bajra-berseem and sorghum-berseem rotation only in the surface soil while subsurface soil remained unaffected.

Rawajfih *et al.*(2010) studied soil phosphorus fractions in calcareous Vertisols and Aridisols of Northern Jordan. The Ca-bound P removed by HCL, was the largest P fraction. The $NaOHCO_3$-P, the non-occcluded Al and Fe-P and the occluded P were insignificant fractions.

While the dominance of Ca-P was not unexpected as per the given calcareous nature of the soils, the relatively high proportion of organic P was surprising given the aridity of the environment.

Trivedi *et al.* (2010) studied forms of phosphorus and their distribution in eighteen profiles of Alfisols and Inceptisols of Grid region of Madhya Pradesh in relation to soil properties. In both orders, amount of Olsen-P, Fe-P, Al-P, Red-P and total-P increased with increasing depth, whereas Ca-P was found to be lower in the surface layers and increased with depth.

Wang Jun *et al.* (2010) a long term field experiment was performed to study the responses of soil inorganic P fractions and P availability to annual fertilizer P application in a calcareous soil on the loess plateau of china. The contents of inorganic P fractions were in the order of Ca_{10}-P > Ca_8-P > Fe-P >Al-P > Occluded P > Ca_2P in the soil receiving annual fertilizer P application. All P fractions but Ca_{10}-P were correlated with Olsen-P significantly 90% of variations in Olsen-P could be explained by P fractions and the direct contribution of Ca-P was predominant.

Amaizah *et al.* (2012) investigated the change in inorganic and organic phosphorus (P) fractions of soil resulting from long term fertilization (40 years). P fractions were extracted from soil sample from depths of 0-30 and 30-60 cm. The results of continuous fertilization during 40 years indicated increase of all the forms of phosphorus in the soil except of phosphorus bond to calcium and organic phosphorus. Application of higher amounts of P fertilizer was the most responsible for the migration of phosphorus along the soil profile.

Dharumarajan and Singh (2014) studied the variation of soil properties and phosphorus fraction in three different cropping systems in Chinchura-Mogra and Pobla-Dadpur block of Hugli District. Organic carbon (0.33%) was recorded higher clay (53.6%), soil reactions (7.14) and cation exchange capacity (17.85 Cmolkg^{-1}). The results from phosphorus fractionation studies shows that soils of plantation system recorded high Olsen-P (3.57 to 10.91 mg kg^{-1}) and Calcium-P (49.20 to 73.56 mg kg^{-1})

whereas paddy-paddy cropping system having high Fe-P (10.46 to 27.83 mg kg^{-1}).

Oja *et al.* (2015) conducted a field experiment on slightly acidic Alfisol. Organic P and Fe-P contributed significantly to the increase in available P while occluded P decreased with an increase in available P.

Chandrakala *et al.* (2017) revealed that there was an increase in total-P, organic-P, reductant soluble-P, occluded-P and calcium-P fractions with the increased gradient strips from very low to very high applied with levels of P. Whereas, saloid-P, aluminium-P and iron-P are the slow plant available labile P forms which were decreased as the P fertility gradients and dose of P addition increased.

Patidar *et al.* (2019) studied phosphorus fractions in representative agricultural soils belonging to three soil orders Vertisol, Inceptisol and Alfisol JNKVV farm, Jabalpur and revealed that Vertisols and Inceptisols were found to be in order of Ca-P>Al-P>Occluded-P>Fe-P>Saloid-P. Whereas, Alfisols in order of Ca-P>Fe-P>Al-P>Occluded-P>Saloid-P. The Ca-P was found high in the Vertisols. But Fe-P and Al-P were recorded maximum under Alfisols.

2.2 Effect on adsorption desorption of phosphorus

Barrow (1974) observed that previously added phosphate was found to occupy phosphate adsorption sites, blocking them from further reaction and reducing the buffering capacity for phosphate.

Smyth (1980) noticed that the previous application of P to soil reduced P adsorption by soil and increased the cations on the soil complex, compared to addition of amendments.

Reddy *et al.* (1980) studied laboratory incubation in which Norfolk soil was treated with beef, poultry, or swine wastes; and allowed to decompose under optimum moisture conditions for a period of 30 days. Phosphorus adsorption-desorption characteristics of the soil were measured at the end of the incubation period. Application of beef, poultry, and swine wastes to a Norfolk soil decreased adsorption capacity of the soil and increased soluble P (in 0.01M $CaCl_2$), acid-extractable P (O.O5N

HCl + 0.025N H_2SO_4), equilibrium P concentration (EPC), and P desorption (after four 1-hour extractions). In a field study, increased rates of swine lagoon effluent application over a period of 5 years to a Norfolk soil (Site 1) and for 3 years to a Cecil soil (Site 2) also increased soluble P (in 0.01M $CaCl_2$), acid extractable P, P desorbed, and EPC values, and decreased the adsorption capacity.

Shailaja and Sahrawat (1990) conducted an experiment to study the effect of various levels of P on adsorption – desorption of P in vertisols during 1990 at ICRISAT. The P adsorbed by a Vertisol (BR-1) fertilized with different rates of P in the previous season (0, 10, 20 and 40 kg P ha^{-1}) was similar (34.3-41.3 mg g^{-1} soil) indicating little effect of fertilization on P adsorption. The correlation studies indicated that the DTPA-extractable Fe was the most important factor accounting for P adsorption in these soils. Clay and $CaCO_3$ content were found to be relatively less important factors affecting P adsorption in the soils studied. The results of study showed that the vertisols studied have less phosphate adsorption capacity and that the P they adsorbed is certainly desorbable.

Sui and Thompson (2000) conducted laboratory experiment on soil samples collected from a field study on a Mollisol amended with three levels of biosolids. Over the range of equilibrium P concentrations in this study, the ability of the soil to sorb added P decreased due to biosolids amendment. The amount of P that could be desorbed from the soil significantly increased after biosolids amendment.

Pinto *et al.* (2013) conducted an experiment in seven soils under native Savannas to study the p-sorption and desorption in savanna brazilian soils. The Langmuir isotherms were adjusted from the values obtained in sorption assays, being evaluated the Maximum Phosphorus Adsorption Capacity (MPAC), the energy adsorption (EA) and P Capacity Factor (PCF), which was calculated according to the levels of P-adsorbed and P-sorbed. Values of MPAC were classified as high in most soils, ranging from 283 up to 2635 mg kg^{-1} of P in the soil and were correlated with soil organic matter, clay, silt, sand, base saturation and pH. The PCF was higher in soils where the MPAC was also higher.

Bhattacharyya *et al.* (2015) conducted an experiment to study the effects of 42-year long-term fertilizer management on soil phosphorus availability, fractionation, adsorption-desorption isotherm and plant uptake in flooded tropical rice, Central Rice Research Institute, Cuttack. The treatments included low-input [unfertilized control without N, P, or K (C_0N_0)], farmyard manure (FYM) (C_1N_0), NP (C_0NP), NPK (C_0NPK), FYM + NP (C_1NP), and high-input treatment, FYM+NPK (C_1NPK). The Fe-P fraction was highest compared to the Ca-P and Al-P fractions after 42 years of fertilizer application and was significantly higher under FYM+NPK treatment. The P adsorption capacity of soil was highest under the low-input treatment and lowest under long-term balanced fertilization (FYM+NPK). In contrast, P desorption capacity was highest under NPK and lowest in the control treatment. Long-term balanced fertilization in the form of FYM+NPK for 42 years lowered the bonding energy and adsorption capacity for P in soil but increased its desorption potential, increasing P availability to the plant and leading to higher P uptake and yield maintenance.

Muindi *et al.* (2015) revealed that the soils that are strongly to extremely acidic (pH 4.83 - 3.76), had high exchangeable Al^{3+} (>2 Cmol Al kg^{-1}), Al saturation of (> 20% Al) and calculated maximal phosphorous adsorption varied from 770.83 to 1795.83 mg kg^{-1} soil. Analysis of relationship between adsorption and soil attributes revealed that adsorption maximum positively correlated with clay content, exchangeable P, exchangeable acidity and Aluminium saturation and negatively correlation with organic matter and electrical conductivity.

Hafiz *et al.* (2016) conducted an experiment on effects of dairy, poultry and goat manure applications on various soil phosphorus sorption indices for a silt loam Bangladeshi agricultural soil. In this experiment the soil was incubated with manures for a month, and sorption experiments were conducted using incubated soil. The soil P adsorption isotherms conformed to S-curve shape for the both manure treated and untreated soils. Adsorption data conformed to the isotherms in the order of Freundlich > Temkin > Langmuir for poultry and goat manure treated soils and Langmuir > Freundlich > Temkin for dairy manure treated soil. Manure treatment decreased all the sorption parameters; the highest decrease was observed from dairy manure treated soil.

Wang (2017) stated that within the experimental concentration range, with the increase of the amount of outer-source phosphorus, P adsorption, desorption and desorption rate increased and adsorption rate decreased gradually in different Olsen-P levels of grey desert soils. The maximum buffer capacity (MBC) and adsorption constant (K) of the NPK treatment was much higher than NPKM, NPKS, PK and CK treatments.

2.3 Effect on yield

Warade *et al.* (1992) observed that amongst the different levels of P, 90 kg P_2O_5 ha^{-1} gave highest 100 grain weight (13.75 gm), grain (10.37q ha^{-1}) and straw yield (15.24 q ha^{-1}) of soybean.

Sharma *et al*. (2002) observed that the application of phosphorus at 60 kg P_2O_5 ha^{-1} produced better yield, dry matter and yield components compare to 30 kg P_2O_5 ha^{-1}.

Umale *et al.* (2002) observed that the application of 75 kg P_2O_5 ha^{-1} gave highest grain weight, grain stover yield, protein and oil content of soybean than 0,25,50 kg P_2O_5 ha^{-1} on Vertisols.

Narayana (2003) conducted an experiment during *kharif* seasons of 1989-91 at Gurazala (A.P.) to study the response of soybean to nitrogen and phosphorus application. It was observed that the grain yield was significantly increased with increasing levels of nitrogen and phosphorus up to 40 and 60 kg ha^{-1} respectively.

Botha *et al.* (2003) observed that the seed and straw yield of soybean was found to be increased with increase in the dose of phosphorus up to 75 kg P_2O_5 ha^{-1}.

Sarawgi *et al*. (2007) conducted an experiment at IGKVV Raipur (C.G.). Plant height dry matter accumulation per plant seed yield per plant and seed yield influenced significantly due to different treatments. All the above parameters were significantly higher with NPK @ 30:60:30 kg/ha

+ 5 t FYM/ha over rest of the treatments. However seeds per pod and 100-seed weight were not influenced due to different treatments. Similarly per cent increase in grain yield was remarkably higher with application of NPK@ 30:60:30 kg/ha + 5 t FYM/ha (64.1%) as compared to control.

Chavan *et al.* (2008) studied the effect of sources (single superphosphate (SSP), diammonium phosphate (DAP) and rock phosphate) and levels of phosphorus (25, 50 and 75 kg P ha^{-1}) with and without phosphate solubilizing bacteria (PSB) inoculation on yield, uptake and economics of soybean. The results revealed that the application of phosphorus through SSP significantly recorded more number of pods, yield $plant^{-1}$, seed and straw yield, phosphorus uptake. Increase in phosphorus level from 25 to 50 and 50 to 75 kg ha^{-1} resulted in significantly increased yield attributes, yield, nitrogen and phosphorus uptake.

Jahangir *et al.* (2009) studied the effect of different levels of nitrogen and phosphorus on yield and yield attributes of soybean. He revealed that the application of 40 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} significantly increased the seed and straw yield of soybean.

Shahid *et al.* (2009) conducted the field experiment was conducted to evaluate the effect of different phosphorus levels viz. 0, 25, 50, 75 and 100 kg ha^{-1} and inoculation with Rhizobium japonicum. 75 and 100 kg ha^{-1} gave significantly better results as compared to other doses of phosphorus.

Bahadur *et al.* (2012) conducted an experiment to study the integrated nutrient management in sodic soil at Dalip Nagar Research Station, Kanpur of C.S.A. University of Agriculture and Technology, Kanpur during 2005-06 and 2006-07 and reported that the phosphorus at 60 and 80 kg ha^{-1} significantly increased the yield and yield attributing characters.

Bhattacharjee *et al.* (2013) conducted a field experiment on an acid alfisol (pH 4.5), with 12 treatments consisting of three levels of P (30, 60 and 90 kg P_2O_5 ha^{-1}), two levels of S (15 and 30 kg S ha^{-1}) and two levels of Co (1 and 2 kg Co ha^{-1}) application in factorial combination. In general, growth and yield parameters of soybean responded positively to higher doses of P, S and Co applications, with the response to P fertilization being the best.He concluded that 60 kg P_2O_5 ha^{-1} along with 15 kg S and 1 kg Co is advisable for optimum growth, yield and quality of soybean on acid alfisols of northeast India.

Dhage *et al*. (2014) conducted an experiment to study the effect of phosphorus and sulphur levels on soybean during 2009-10 and 2010-11 at Research Farm Department of Soil Science and Agril. Chemistry, MKV, Parbhani (MS) on Vertisol. The treatment consisted of four levels of phosphorus (P_0, P_{30}, P_{60} and P_{90} kg P_2O_5 ha $^{-1}$) and four levels of sulphur (S_0, S_{20}, S_{40} and S_{60} kg ha^{-1}) applied through DAP and elemental sulphur, respectively. Result indicated that grain and straw yield, uptake of phosphorus and sulphur increased with increase in the rate of application of P and S individually as well as in various combinations. Available P in soil also increased with increasing levels of phosphorus.

Khaswa *et al*. (2014) conducted an experiment to study the growth, productivity and quality of soybean [*Glycine max (L) Merrill*) under different levels and sources of phosphorus and plant growth regulators in sub humid Rajasthan. Results indicate that 40 kg P_2O_5 ha^{-1} SSP and NAA recorded significantly higher pooled plant height (51.65, 50.82 and 51.17 cm), branches $plant^{-1}$(4.56, 4.43 and 4.48), oil content (21.40,20.91 and 21.20%), oil yield (558.89, 528.75 and 521.79 kg ha^{-1}), seed protein yield (1111.56, 1039.96 and 1045.60 kg ha^{-1}), grain yield (25.95, 25.12 and 24.23 q ha^{-1}) and Stover yield (37.37, 36.23 and 35.73 q ha^{-1}) over their corresponding treatments.

Lad *et al.* (2014) studied the four levels of each nitrogen (0, 50, 100 and 150 kg ha^{-1}) and phosphorus (0, 25, 50 and 75 kg P_2O_5 ha^{-1}) and their impact on growth, yield attributes, yield and economics of French bean grown on Vertisols. Application of 150 kg N ha^{-1} and 75 kg P_2O_5 ha^{-1} significantly increased the highest grain and straw yield of French bean and show at par result with crop receiving 100 kg N and 50 kg P_2O_5 ha^{-1} which was found more profitable.

Begum *et al.* (2015) studied the effect of nitrogen and phosphorus on the performance of soybean. Three levels of nitrogen (0, 25 and 40 kg N ha^{-1}) and four levels of phosphorus (0, 18, 36 and 54 kg P ha^{-1}) were applied. Combined application of 25 kg N with 54 kg P ha^{-1} significantly increased seeds plant^{-1}, number of filled pods plant^{-1}, weight of seeds plant^{-1}, dry weight of plant^{-1}, stover weight plant^{-1} 1000 seed weight, seed and stover yield.

Laharia *et al.* (2015) conducted an experiment to study the interactive effect of phosphorus and zinc on yield, quality and nutrient use efficiency of soybean. Application of 100 percent RDP i.e. 30:75:30 NPK kg ha^{-1} with 5 kg zinc ha^{-1} were recorded higher soybean yield, uptake of nutrients as well as maximum nutrient use efficiency (NUE) and nutrient recovery by soybean.

Khanam *et al*. (2016) conducted a field experiment at the Sher-e-Bangla Agricultural University Farm, Dhaka, Bangladesh during December 2013 to April 2014 to evaluate the effect of phosphorus (P0: 0 kg TSP ha^{-1}, P1: 100 kg TSP ha^{-1}, P2: 175 kg TSP ha^{-1}, P3: 250 kg TSP ha^{-1}) and potassium (K0: 0 kg MOP, K1: 60 kg MOP ha^{-1},K2: 120 kg MOP ha^{-1}, K3: 180 kg MOP ha^{-1}), and their combinations on growth and yield of soybean (Glycine max). Number of nodules plant, number of filled pods plant, number of seeds pod, 1000-seed weight, seed yield, biological yield and harvest index increased significantly up to 175 kg ha^{-1} TSP. On the other hand, numbers of nodules plant, number of filled pods plant, length of pod, and number of seeds pod, 1000-seed weight, seed yield, stover yield and biological yield were enhanced significantly up to 120 kg ha^{-1} MOP. The treatment of combined phosphorus @ 175 kg ha^{-1} and potassium @ 120 kg MOP ha^{-1} depicted the highest number of filled pods plant (63.00), length of pod (3.16 cm), number of seeds pod (3.11) viz. the highest (3.67 t ha^{-1}) seed yield. Thus, the combined application of 175 kg ha^{-1} TSP and 120 kg ha^{-1} MOP could be the optimum for getting maximum yield of soybean.

2.4 Effect on nutrient uptake

Upadhyay *et al*. (1994) stated that Potassium content in seed of soybean was ranged from 0.81 to 0.86 per cent and increased with increase in P rates.

Patel and Chandravanshi (1996) revealed that application of phosphorus increased the concentration of nitrogen and phosphorus in soybean seed and straw.

Nale (1996) reported that P uptake by soybean grain and straw was higher and significantly influenced by increasing level of phosphorus and was highest in 100 kg P_2O_5 ha^{-1} treatment. Similar increase in uptake of phosphorus in legume was observed on application of fertilizer.

Nimje and Potkile (1997) reported that the chlorophyll content, total plant N, root nodule N, plant P and plant K content of chickpea was increased with applied P rate.

Dubey (1997) revealed that seed yield and N, P and K uptake in soybean were higher at 30 kg P_2O_5 ha^{-1} through single super phosphate along with *Pseudomonas striata*.

Nimje and Seth (1998) observed that phosphorus fertilization to soybean significantly increased the concentration and uptake of N, P and K at flowering and harvesting stage. Application of 80 kg P_2O_5 ha^{-1} proved significantly superior over 40 kg ha^{-1} and control.

Kumar (1998) reported that application of 40 kg P_2O_5 ha^{-1} significantly increased the N and P content in seed and straw and their uptake by cowpea over control and 20 kg P_2O_5 ha^{-1}.

Chafle *et.al* (1999) indicated that the highest N, P, and K uptake were recorded by application of 30 kg N and 90 kg P_2O_5 ha^{1} through urea and SSP over other treatments.

Navale *et al.* (2000) observed that the application of 60 kg N + 120 kg P_2O_5 ha^{-1} resulted significantly higher uptake of N and P than rest of the treatments. However, in case of K uptake, the application of 60 kg N + 120 kg P_2O_5 ha^{-1} was found at par with 40 kg N + 80 kg P_2O_5 ha^{-1}.

Dikshit and Khatik (2002) reported that 50% of recommended dose of NPK+10 tonnes FYM ha^{-1} enhanced the availability N, P, K and S in soil and uptake by soybean as well as recorded the highest grain (16.00 q ha^{-1}) and straw (30.75 q ha^{-1}) yields.

Tiwari *et al*. (2002) observed that the inclusion of FYM in the treatment schedule improve the organic carbon status and available N, P, K and S in soil there by, sustaining the soil health. They have also reported that the status of available K in soil was found to decrease in all the treatments but the decrease was of lower magnitude in 100% NPK + FYM and 150% NPK treatments indicating the need to raise the level of K fertilizer application to meet the demand of the crops.

Laharia *et al.* (2004) studied the effect of N rates (0, 15, 30, 45, 60 and 75 kg ha^{-1}) on soybean yield and nutrient uptake at different stages. N fertilizers showed favourable effects on yield and yield contributing characters. N fertilizer enhanced dry matter accumulation compared to the control at all critical stages of plant growth. N, P and K uptake of soybean progressively increase flowering to harvesting stage.

Bharambe and Tomar (2004) studied a field experiment on vertisols and reported that P and K uptake was significantly increased with the application of FYM and fertilizer.

Chaturvedi and Chandel (2005) reported at Pantnagar that the application of 100% recommended dose of NPK + FYM @ 10 t/ha increased the NPK-uptake in soybean.

Govindan and Thirumurugan (2005) observed that the combined (Rhizobium + PSB) inoculation of bio-fertilizers, significantly increase the NPK uptake and post-harvest soil N and P levels.

Dhawan *et al*. (2006) reported that application of vermicompost @ 5 t/ha resulted in significantly higher grain and straw yield of soybean along with their P uptake over no application of vermicompost.

Jadhav *et al*. (2007) reported that application of fertilizer for 20 q/ha target yield with 5 tonnes FYM and bio-fertilizers, soybean grains showed significant increase in concentration of N, P and Mg.

Singh *et al*. (2007) reported that the bio-fertilizer + recommended dose of fertilizer (RDF) significantly increased N and K-uptake over control.

Bhattacharyya *et al*. (2008) observed that the total removal of K by the crops exceeded K applied to the soil in all the treatments showing a net negative K balance ranging from 3.7 (in NK-treated plots) to 81.7 kg/ha/year (in N + FYM-treated plots).

Kumar *et al.* (2010) observed that application of phosphorus @ 40 kg P_2O_5 ha^{-1} significantly increased the nitrogen by lentil (57 kg ha^{-1}) and stalk (22 kg ha^{-1}) at harvest over 20 and 0 kg P_2O_5 ha^{-1}.

Arbad and Ismail (2011) reported at Parbhani that the maximum nutrient total uptake of N, P and K in soybean and safflower was due to application of 100% NPK + FYM @ 10 mg/ha.

Sharma *et al*. (2011) observed that application of phosphorus to soybean @ 60 kg P_2O_5 ha^{-1} significantly increased nitrogen uptake (110 kg ha^{-1}), potassium uptake (43.4 kg ha^{-1}) and phosphorus uptake increased from 3.7 to 9.6 kg ha^{-1} over 30 and 0 kg P_2O_5 ha^{-1}.

2.5 Effect on chemical properties of soil

Gattani *et al*. (1976) reported that non-significant change in soil pH due to continuous use of chemical fertilizer and manure, except in the case of NPK and NK treatment where pH had slightly lowered.

Dwivedi *et al*. (1989) studied the effect of different phosphatic fertilizers under soybean-wheat system in Inceptisols and observed that gradual increase in phosphorous availability with increasing level of P.

Mathur (1997) indicated that application of 100% NPK , 50% NPK+ 50% FYM and 100% FYM significantly increased available phosphorous (68.88, 63.39, 58.76 and 52.88 kg P_2O_5 ha^{-1}) respectively as compared to initial (14.40 kg P_2O_5 ha^{-1}).

Bhoyar and Ingle (1998) studied effect of manures and fertilizers on the physico-chemical properties of Vertisols under sorghum-wheat crop sequences and shown that organic carbon content of the surface and sub-surface soil was significantly influenced by different treatments.

Yadav (1998) conducted field experiment with different nitrogen and phosphorus levels at four locations in India and observed that long-term fertilization decreases available nitrogen status of soil at two locations.

Ghosh *et al.* (2001) reported that organic carbon was maintained in NPK treated plots or slightly increased due to huge biomass/ leaf fall of soybean. Organic carbon has increased significantly in FYM treated plot in last five years average in soybean-wheat cropping system.

Chaturvedi *et al.* (2005) studied the influence of organic and inorganic fertilization on soil fertility and productivity of soybean and observed that, use of organic sources helped in maintaining soil fertility in terms of available nutrients. The higher nitrogen phosphorous and potassium were recorded with application of RDF with FYM @ 10 t ha^{-1} showing 24.0, 10.3 and 4.3 kg ha^{-1} over the control respectively.

Yadav *et al.* (2010) revealed that the slight decrease in pH and EC and increase in organic carbon, available phosphorus and sulphur after harvest of mustard was recorded by application of phosphorus @40 kg ha^{-1}.

Amba *et al.* (2011) reported that pH, organic carbon, total nitrogen and available phosphorus increased with application of different levels of phosphorus fertilizers. Phosphorus fertilizer application significantly increased nitrogen fixation up to 26.4 kg P ha^{-1}, but declined significantly at higher levels of 39.6 kg P ha^{-1} in the cropping seasons.

Meena *et al.* (2013) conducted a study on the long-term effect of fertilizers and amendments on crop productivity and changes in soil fertility and revealed that the status of available nitrogen (N) and potassium (K) declined over the years in all the treatments.

Dwivedi *et al.* (2015) studied on the soil test for improving soybean productivity which was a mandatory part of a program at Agriculture Science Center, Rewa in Madhya Pradesh (MP) of India. Soils of studied area had pH 6.8 to 7.4, EC 0.17 to 0.23 dSm^{-1}, organic carbon 0.33 to 0.71 per cent available nitrogen 105 to 214 kg ha^{-1} phosphorus 7.30 to 16.80 kg ha^{-1}.

Mathew *et al.* (2018) observed that soil nitrogen reduced within the lower level and still remained low even after phosphorus level treatments were applied though negligible net increase was elicited as a result of each treatment across the seasons. The highest net increase of 0.05 per cent was observed on the 75 Kg ha^{-1} P_2O_5 treatment and control in season 1. The treatment of 50 Kg ha^{-1} P_2O_5 had the lowest net increase of 0.02 per cent in season 2. There was no significant difference on the net increase of soil nitrogen as a result of the phosphorus level applications in both seasons.

2.6 Effect on nodulation and roots

Cassman *et al*. (1980) reported that a decrease in the Phosporus supply inhibited nodule growth relatively more than either root or shoot growth. For soybean, decrease in the P supply affected shoot growth relatively more than either nodule or root growth. When grown at intermediate P levels (0.02 to 0.5 µ/ml), the root + nodule: total plant dry weight ratio was similar in both N-fixing and N applied plants. However, the root : total plant dry weight ratio of N-fixing plants was less than that of Nitrogen supplied plants at P levels.

Borkert and Barber (1985) investigated the effect of P-fertilized soil volume on soybean root growth and revealed that total root length per pot showed a significant increase for P-added treatments over the treatment without P. The distribution of root dry weight and root length between fertilized and unfertilized soil indicated a stimulation of root growth in the P-fertilized portion of the soil. This stimulation gave longer finer roots and increased root surface area, which should increase P uptake.

Prasad *et al.* (1993) revealed that application of 60 kg P_2O_5 ha^{-1} to soybean influenced significantly dry weight and number of nodules $plant^{-1}$.

Goswami *et al.* (1999) observed that among the different levels of phosphorus to soybean @ 20,40 and 60 kg ha^{-1}, the maximum plant height (67.93 cm), branches (3.51) leaves $plant^{-1}$ (16.52) at 75 DAS and root nodules $plant^{-1}$ (29.88) at 60 DAS were recorded with the application of 60 kg P_2O_5 ha^{-1}.

Tsvetkova and Georgiev (2003) conducted field experiment on effect of phosphorus nutrition on the nodulation, nitrogen fixation and nutrient use efficiency of bradyrhizobium japonicum – soybean symbiosis and observed that the changes in P supply decreased fresh and dry weight of nodule by almost 50%, in both P deficient and P oversupplied plants. The excess of P decreased nodule number up to the 35% in comparison with control. Nodulation of P-deficient soybean was less affected, but most of the nodules showed smaller size in comparison with the control.

Singh and Pareek (2003) from an experiment on sandy loam soil Rajasthan reported that application of phosphorus @ 45 kg P_2O_5 ha^{-1} significantly increased nodule dry weight over 60, 30, 15 kg P_2O_5 ha^{-1} and no phosphorus application.

Jain and Trivedi (2005) revealed that there is significant increased nodule number of soybean with increase in phosphorus application from 13.2 to 26.2 kg P_2O_5 ha^{-1}.

Jin *et al.* (2005) conducted field experiment and observed that with increase in the phosphorus level, the root length and surface area significantly increased.

Kakad (2005) indicated that the application of phosphorus @75 kg P_2O_5 ha^{-1} recorded significantly higher number of root nodules $plant^{-1}$ at flowering. The grain and straw yield, N, P, K content, total uptake of N, P, K, Zn, oil and protein contents were also increased.

Asghar *et al.* (2006) observed that nodule number increased with increasing phosphorus level from 0 to 45 kg P_2O_5 ha^{-1}.

Abbasi *et al*. (2008) revealed that application of 50 kg P_2O_5 ha^{-1} + combination of S77 + S79 *Bradyrhizobium japonicum* recorded higher nodule number $plant^{-1}$ (86.5) and dry weight of nodules (0.92 g $plant^{-1}$) compared to other treatments in soybean.

Devi *et al*. (2012) concluded that application of SSP+PSB produced significantly higher number of nodules per plant, dry weight of nodules per plant, number of pods per plant and 100-seed weight than the other treatments. Maximum grain yield and total phosphorus uptake were also recorded when using SSP+PSB. Yield attributing characters, grain and stover yield were increased with increasing levels of phosphorus.

Amba *et al.* (2013) observed that application of nitrogen at 20 kg N/ha significantly ($P \leq 0.05$) reduced number of nodules at 2 week after sowing (WAS) only. On the other hand, application of phosphorus at 26.4kgP/ha significantly ($P \leq 0.05$) produced higher number of nodules throughout the study period than the other levels used. Amongst the legumes, groundnut consistently and significantly ($P \leq 0.05$) gave higher number of nodules than cowpea and soybean.

Darwesh *et al.* (2013) conducted a pot experiment to study the effect of different phosphorus fertilizers on growth and nutrient status of soya bean cultivars. The treatments including, the phosphorus fertilizers (P1=Control no fertilizer, P2=Triple super phosphate, P3=Di ammonium phosphate, P4=Di potassium phosphate, P5=NPK 20:20:20 with some trace elements and P6=NPK 12:36:12 with Mg) each of them applied in 75 Kg P ha^{-1}. The result indicates that the highest values for shoot dry matter and root dry matter were given by the application superphosphate fertilizers via enhancing the root growth and increasing the root hair length.

Jin *et al.* (2013) conducted a pot experiment to determine the morphological characteristics of lateral roots of different orders and P acquirement of soybean seedlings under three levels of P (0, 50 and 100) mg P kg^{-1} soil and revealed that Phosphorus application significantly increased dry weight, total length and number of lateral roots in the four orders with the ranking of fourth > third > second > first .

Lamptey *et al.* (2014) conducted a field experiment on response of soybean (glycine max) to rhizobial inoculation and phosphorus application and revealed that significant increase in number of nodules, weight of dry nodules, weight of dry shoots and yield weight with rhizobium inoculants and application of phosphorus from different source and recommends the use of rhizobium inoculants in treating soybean seeds before sowing and application of Triple superphosphate fertilizer at 30 kg P ha^{-1}.

Nkaa *et al*. (2014) revealed that soil application of phosphorus @ 80 kg ha^{-1} significantly increased the nodule dry weight over 60, 40 and 20 kg of P_2O_5 ha^{-1}.

Zou *et al.* (2015) observed significantly more root proliferation in the form of root length, root surface area, root volume, and root dry matter accumulation in P-replete than in P-poor patches when the patch persisted for a short period of time (50 days).

Spandana *et al.* (2016) conducted field experiment with three levels of phosphorus (0, 30 and 60 kg P_2O_5 ha^{-1}) and revealed that growth parameters and yield attributes viz; plant height, number of branches, number of pods $plant^{-1}$, root length and volume were significantly higher with the increment in phosphorus application up to 60 kg ha^{-1}.

CHAPTER III

MATERIAL AND METHODS

The field experiment on topic entitled ”Phosphorus adsorption – desorption as influenced by various levels of phosphorus under soybean grown in Vertisols” was initiated during 2017-18 and the present study was conducted during 2019-20 on the Research Farm, Department of Soil Science and Agricultural Chemistry, Dr. PDKV, Akola. The details of material used and methods adopted during the course of investigation are described below under appropriate heads.

3.1 Material required
3.1.1 Climate and weather conditions
3.1.2 Soil of experimental area
3.1.3 Experimental site
3.2 Experimental details
3.2.1 Collection and preparation of soil samples for analysis
3.2.2 Sources and application of fertilizer
3.2.3 Methods adopted for soil analysis
3.2.4 Plant analysis
3.3 Statistical analysis

3.1 Material Required

3.1.1 Climate and weather conditions

Akola is situated in the subtropical region at 22°42' North latitude and 77°02' East longitude and altitude of 307.42 m above the sea level. The climate of Akola is semi-arid and characterized three distinct season viz., hot and dry summer from March to May, warm and rainy monsoon from June to October and mild cold winter from November to February. Average annual precipitation is 711.1 mm. The normal mean monthly maximum temperature is 34.4^{0}C during the hottest May. While the normal mean monthly minimum temperature is 8.4^{0}C in the coldest December.

The mean daily evaporation reaches as high as 6.1 mm in the month of June and as low as 3.4 mm in the month of December. The mean wind velocity varies from 4.7 km hr^{-1} during June.

Table 1: Weekly Weather data for the year 2019 recorded at Meteorological Observatory Department of Agronomy Dr. PDKV., Akola

		Actual				2019									Normal			1981-2010		
Weeks	Dates	T Max (ºC)		T Min (ºC)		BSH (hrs)		WS (km/hr)		R I (%)		RH II (%)		Evap (mm)		RF (mm)		CRF (mm)	Rainy Days	
		N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A		N	A
22	28-3 Jun	41.8	44.6	28.0	27.9	9.1	9.3	14.5	9.7	52	39	23	16	15.6	15.9	5.3	0.0	15.4	0.4	0.0
23	4-10	40.5	43.2	27.0	26.2	8.3	7.6	14.0	11.4	62	54	30	22	13.7	16.8	19.3	4.7	20.1	1.3	1.0
24	11-17	37.8	41.6	25.8	26.3	7.1	9.1	12.8	10.3	70	49	42	25	10.5	15.2	42.2	2.8	22.9	1.9	1.0
25	18-24	35.3	38.5	25.0	23.3	5.4	6.6	13.7	9.8	75	66	48	40	8.7	10.6	44.3	47.7	70.6	2.0	1.0
26	25-1Jul	34.0	33.8	24.6	21.2	5.0	5.2	12.7	5.5	79	84	53	54	7.4	8.0	41.6	34.4	105.0	1.8	3.0
27	2-8	33.3	30.2	24.3	20.0	4.9	0.7	11.6	9.4	80	89	57	68	6.5	4.6	36.3	53.8	158.8	2.1	6.0
28	9-15	32.6	33.5	24.1	21.5	4.0	4.5	10.7	8.3	82	78	59	49	5.6	6.3	40.7	22.4	181.2	2.4	1.0
29	16-22	31.7	34.9	23.7	21.8	3.7	7.1	9.6	6.2	85	79	65	48	4.8	7.6	61.5	27.3	208.5	2.6	2.0
30	23-29	30.8	31.6	23.4	20.9	3.5	4.7	10.6	7.8	86	88	66	69	4.4	5.0	42.9	106.1	314.6	2.8	5.0
31	30-5 Aug	30.8	27.6	23.4	19.6	3.3	0.7	10.2	9.0	86	92	67	82	4.2	2.9	44.4	118.7	433.3	2.3	5.0
32	6-12	29.8	29.1	23.1	20.1	3.1	2.2	10.5	8.5	88	90	71	73	3.8	4.4	58.4	79.0	512.3	2.9	2.0
33	13-19	30.4	30.5	23.2	20.1	3.8	4.2	10.4	6.0	87	88	67	67	4.3	4.5	34.3	10.9	523.2	2.0	2.0
34	20-26	30.4	29.6	23.0	20.0	4.0	3.1	9.2	7.7	87	90	66	76	4.1	4.3	37.6	28.5	551.7	1.8	3.0
35	27-2 Sep	30.6	29.1	22.8	19.9	4.3	3.3	9.0	4.6	87	91	65	72	4.2	4.0	40.1	54.5	606.2	2.1	3.0
36	3-9	31.0	29.6	22.6	20.6	5.0	1.9	8.3	4.0	87	92	63	77	4.3	2.7	35.0	9.0	615.2	1.6	1.0
37	10-16	32.1	29.0	22.5	19.9	6.3	1.7	7.3	8.0	85	90	57	75	4.8	2.9	25.3	18.0	633.2	1.3	3.0
38	17-23	32.5	30.3	22.4	19.4	6.2	2.8	6.1	1.2	85	94	56	70	4.8	2.2	26.5	118.1	751.3	1.7	4.0
39	24-30	33.3	30.6	22.2	19.5	7.0	4.5	4.8	1.3	85	94	51	67	4.6	3.1	23.7	82.0	833.3	1.3	4.0
40	1-7 Oct	33.6	32.3	21.2	20.0	7.4	7.6	4.3	1.5	82	90	48	57	4.9	4.7	25.3	6.4	839.7	1.2	1.0
41	8-14	33.8	32.3	19.9	17.9	7.8	8.1	3.5	0.6	79	88	41	48	4.9	4.3	14.5	0.0	839.7	0.7	0.0
42	15-21	33.3	30.5	18.1	16.5	7.9	5.0	3.6	0.8	78	91	37	58	4.8	3.9	7.5	11.2	850.9	0.5	1.0
43	22-28	33.0	26.8	16.3	17.6	8.2	0.7	3.3	0.8	74	95	33	79	5.0	2.2	5.9	67.5	918.4	0.4	5.0
44	29-4 Nov	32.6	30.3	15.8	18.0	8.2	4.9	3.7	0.5	74	93	32	61	5.0	3.1	1.9	11.8	930.2	0.2	1.0
45	5-11	32.2	31.3	15.3	16.4	8.2	7.5	3.6	0.5	72	90	33	50	4.8	3.5	3.2	0.0	930.2	0.3	0.0
46	12-18	31.4	30.2	14.5	11.9	8.1	8.0	3.4	0.9	74	90	33	40	4.4	3.9	7.1	0.0	930.2	0.3	0.0
47	19-25	30.8	30.3	13.0	13.4	8.3	7.9	3.1	0.5	72	89	29	40	4.2	3.8	4.5	0.0	930.2	0.2	0.0
48	26-2 Dec	30.7	30.3	12.5	15.6	8.4	7.2	3.2	0.7	70	90	30	44	4.2	3.5	3.8	0.0	930.2	0.3	0.0
49	3-9	30.2	29.0	11.6	14.8	8.2	7.0	3.4	1.0	70	83	30	37	4.1	4.2	2.1	0.0	930.2	0.3	0.0
50	10-16	29.7	29.5	11.0	16.6	8.1	5.9	3.2	0.7	71	89	29	49	4.0	3.1	2.0	1.2	931.4	0.3	0.0
51	17-23	29.5	27.2	10.6	15.8	8.3	4.1	3.4	0.2	70	90	28	49	3.9	2.9	2.0	0.0	931.4	0.3	0.0
52	24-31	29.0	25.9	10.8	13.5	8.0	3.9	3.5	1.1	72	81	31	47	3.9	3.7	4.5	13.0	944.4	0.5	2.0
2020																				
1	1-7 Jan	28.7	23.1	11.0	13.1	7.9	3.6	4.0	1.9	74	89	32	57	3.9	3.5	3.1	0.0	0.0	0.2	0.0
Total rainfall from June to Jan.																				
Total rainfall from Jan. to Jan.																				

3.1.2 Soil of experimental area

The soil of experimental site was Vertisols which contains smectic type of clay minerals. The initial soil samples were analyzed and fertility status at the start of the experiment is presented in table 2.

Table 2: Initial chemical properties of experimental site

Sr. No.	Soil properties	Value
	Chemical properties	
1.	pH (1:2.5)	8.42
2.	EC (dSm^{-1})	0.25
3.	Organic carbon ($g\ kg^{-1}$)	5.92
4.	Calcium carbonate (%)	6.32
5.	Available N ($kg\ ha^{-1}$)	150
6.	Available P ($kg\ ha^{-1}$)	10.66
7.	Available K ($kg\ ha^{-1}$)	387

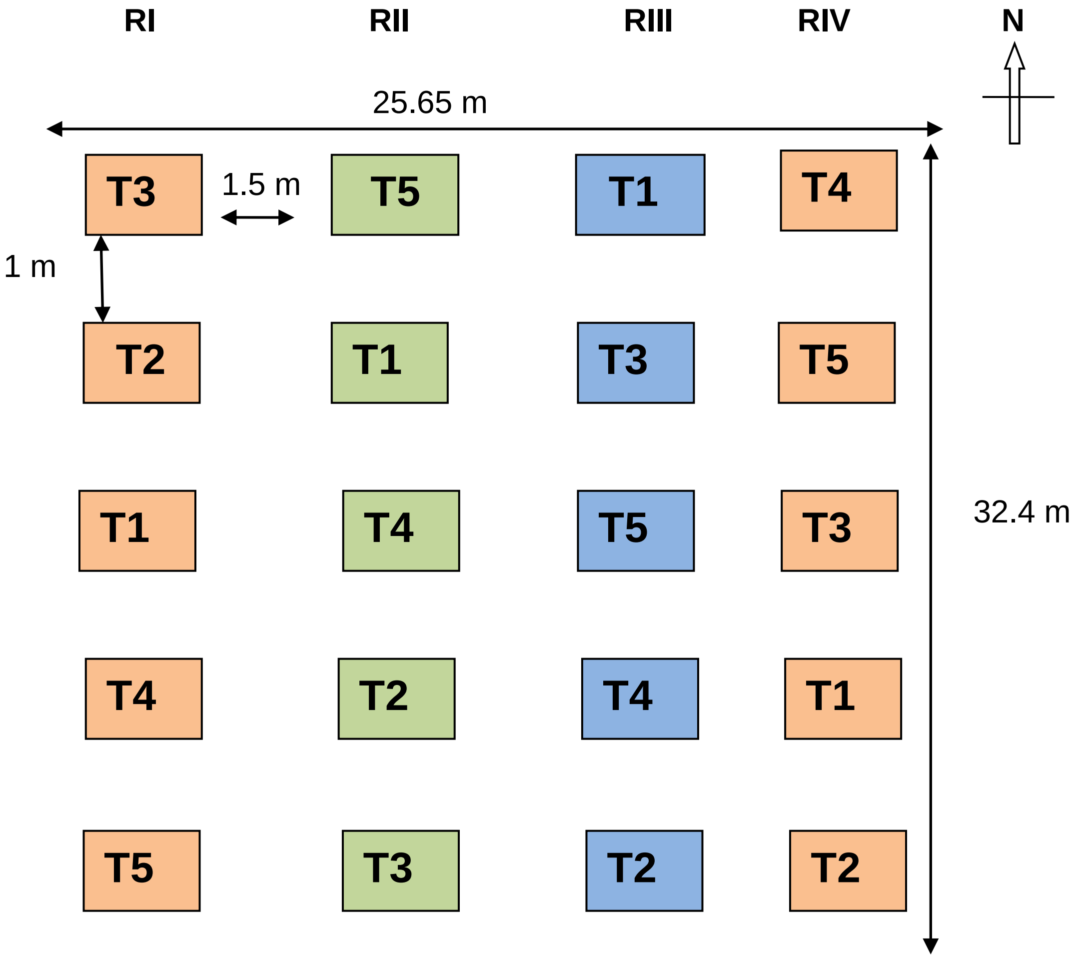
3.1.3 Experimental site

The present investigation was conducted during the *kharif* season, 2019-20 at Research farm, Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The plan of layout is given in Plate 1.

3.2 Experimental details

This experiment was conducted with five treatments and four replications laid out in a randomized block design at Research farm, Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra.

Details of each treatment and information pertaining experimental site are given below.



Plot size : Gross – 5.4 X 6.0 m^2

Net – 4.5 X 5.7 m^2

Design : Randomized Block Design (RBD)

Treatments : 5

Replications : 4

Plate 1. Experimental layout

Details of Experiment

1.	Location	Research Farm, Department of Soil Science and Agril Chemistry, Dr.PDKV.Akola
2.	Year of start	2017-18
3.	Year of study	2019-20
4.	Soil type	Vertisols
5.	Crop and Variety	Soybean (JS-335)
6.	Season	*Kharif*
7.	Design of Experiment	Randomized Block Design (RBD)
8.	Treatments	05
9.	Replications	04
10.	Spacing	45 x 5 cm
11.	Plot size	Gross:5.4 x 6.0 m^2
		Net : 4.5 x 5.7 m^2
12.	Seed rate	75 kg ha^{-1}
13.	Method of sowing	Drilling
14.	Recommended dose of fertilizer	30:75:30 N, P_2O_5, K_2O Kg ha^{-1}
15.	Date of sowing	04/07/2019
16.	Date of harvesting	15/11/2019

Table 3: Treatment details

Tr.	Treatment Details
T1	Absolute Control
T2	45 kg P_2O_5 ha^{-1}
T3	60 kg P_2O_5 ha^{-1}
T4	75 kg P_2O_5 ha^{-1}
T5	90 kg P_2O_5 ha^{-1}

Note: The common dose of 30 kg N and 30 kg K_2O ha^{-1} applied to all treatments except control.

Plate 2. Overview of field experiment

3.2.1 Collection and preparation of soil samples

The representative soil samples (0-20 cm) were collected from each plot of experimental area before sowing and after harvest of crop by using soil auger. The soil samples were air dried in shade to preserve the organic carbon content in soil and grounded by using wooden pestle and mortar with care and then passed through 2 mm sieve. The sieved samples were well mixed and then stored in polythene bags and properly labelled for subsequent analysis.

3.2.2 Sources and application of fertilizer

The nitrogen, phosphorus, potassium applied in the form of Urea, Single super phosphate, Muriate of potash, respectively. Treatment wise basal dose of fertilizers were applied at the time of sowing.

3.2.3 Methods adopted

Soil chemical analysis

3.2.3.1 Soil reaction (pH)

Hydrogen ion activity expressed as pH was measured with pH meter using 1:2.5 soil-water suspension (Jackson, 1973).

3.2.3.2 Electrical conductivity (EC)

The clear supernatant extract obtained from soil-water suspension used for pH was utilized for the measurement of EC using conductivity bridge (Jackson, 1973).

3.2.3.3 Organic carbon

Walkley and Black Wet oxidation method as described by Jackson (1973) was used to determine organic carbon content in soil.

3.2.3.4 Calcium Carbonate ($CaCO_3$)

Calcium Carbonate was determined by Rapid Titration Method by (Piper, 1966)

3.2.3.5 Available nitrogen

Alkaline Potassium Permanganate Method as described by Subbiah and Asija (1956) was used to determine available nitrogen content in soil.

3.2.3.6 Available phosphorus

It was determined by Olsen's method using 0.5 M sodium bicarbonate (pH- 8.5) as extractant. Darco-G-60 soluble charcoal was used to absorb the dispersed organic matter and make the filtrate colourless for using UV based double beam spectrophotometer (Watanabe and Olsen, 1965).

3.2.3.7 Available potassium

Available potassium was determined by Neutral normal ammonium acetate using Flame Photometer (Knudsen and Peterson, 1982)

3.2.3.8 Phosphorus Adsorption and Desorption

Phosphorus Adsorption was determined by 0.01M $CaCl_2$ extraction method and Phosphorus Desorption was determined by 0.01M $NaHCO_3$ extraction method (Fox and Kamprath, 1971)

3.2.3.9 Inorganic P fractions (Al-P, Fe-P, Ca-P)

Inorganic P fractions (Al-P, Fe-P, Ca-P) was determined by Modified sequential P extraction method (Peterson and Corey 1966).

3.2.3.10 Buffering capacity

Buffering capacity was computed by the formula given by Bowman and Olsen (1985a, 1985b).

Buffeing capacity = $\Delta Q / \Delta I$

Where,

Q = Quantity (P in solid phase)

I = Intensity (P in solution phase)

ΔQ = Change in Q

ΔI = Change in I

3.2.4 Plant analysis:

Nutrient content

3.2.3.1 Nitrogen

Nitrogen in the plant sample was determined by Micro Kjeldahl Method (Piper 1966)

3.2.3.2 Phosphorus

Phosphorus in the plant sample was determined by Vanado-phospomolybdate yellow colour method using diacid extract (Jackson, 1973)

3.2.3.3 Potassium

Potassium in the plant sample was determined by Flame photometer using diacid extract (Piper, 1966)

3.2.3.4 Root length and volume

Root length and root volume was determined by Modified Root Intersect Method (Tennant, 1975) and by Displacement method.

3.3 Statistical analysis

The statistical significance to the experimental data was carried out as per procedure described by Gomez and Gomez (1984).

CHAPTER IV

RESULTS AND DISCUSSION

The results obtained from the field experiment entitled "Phosphorus adsorption – desorption as influenced by various levels of phosphorus under soybean grown in Vertisols" conducted at Research Farm, Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during *Kharif* 2019-20 and results of laboratory analysis of soil and plant are tabulated, interpreted and discussed in this chapter under the following heads.

Effect of various levels of phosphorus application on:

4.1 Inorganic forms of Phosphorus (Al-P, Fe-P, Ca-P)

4.2 Phosphorus Adsorption-Desorption

4.3 Grain and Straw yield of soybean

4.4 Nutrient content in soybean

4.5 Uptake of nutrient by soybean

4.6 Chemical properties of soil

4.7 Number and dry weight of nodules of soybean at 60 DAS

4.8 Root length and volume at 60 DAS

4.1 Inorganic forms of Phosphorus (Al-P, Fe-P, Ca-P)

The data in concern to inorganic forms of phosphorus i.e. Al-P, Fe-P, Ca-P has been presented in table 4 and Fig. 1. The table showed that there is significant increment in order of Ca-P>Fe-P>Al-P. The Al-P values ranged from 8.44 to 19.77 mg kg^{-1}, Fe-P ranged from 13.69 to 24.32 mg $kg^{-1}$and Ca-P ranged from 37.92 to 59.28 mg kg^{-1} respectively. The Ca-P is the fraction of soil phosphorus that can be readily adsorbed by growing plants.

The high values of Ca-P than Fe-P and Al-P might be due to the alkaline pH of soil. Usually, the high fixation of phosphate in alkaline soils by calcium than iron and aluminium are observed.

The results are closely in agreement with the findings of Tembhare and Kaushal (2000), Pandian and Jothimani (2001) and Murthy *et al.* (2002).

Table 4: Effect of various levels of phosphorus on Inorganic forms of Phosphorus (Al-P, Fe-P, Ca-P)

Treatments	Inorganic forms of Phosphorus (mg kg^{-1})		
	Al - P	**Fe - P**	**Ca - P**
T_1 - Absolute Control	8.44	13.69	37.92
T_2 - 30:45:30 kg N, P_2O_5 & K_2O ha^{-1}	10.69	17.06	40.00
T_3 - 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}	13.54	19.83	46.12
T_4 - 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}	16.36	22.45	56.31
T_5 - 30:90:30 kg N, P_2O_5& K_2O ha^{-1}	19.77	24.32	59.28
SE (m) ±	0.37	0.337	0.414
CD at 5 %	1.152	1.051	1.290

4.2 Phosphorus Adsorption – Desorption

Adsorption and desorption of phosphorus in soils are among the key processes governing its availability to crops. Adsorption isotherm is an important criterion which has been used to estimate phosphorus concentration in aqueous phase of soil, energy of phosphorus adsorption, buffer strength of soil against phosphorus concentration variations in solution and equilibrium state between phosphorus in aqueous and solid phases.

The isotherms are explained by fitting of the isotherms and their mathematical descriptions using Langmuir, Freundlich, Tempkin isotherm models.

The data in respect of phosphorus adsorption and desorption has been presented in table 5, 6 and Fig. 2, 3. The P adsorption at 20 ppm conc. of P in equilibrium solution is ranged from 5.40 to 7.80 mg kg^{-1} and at

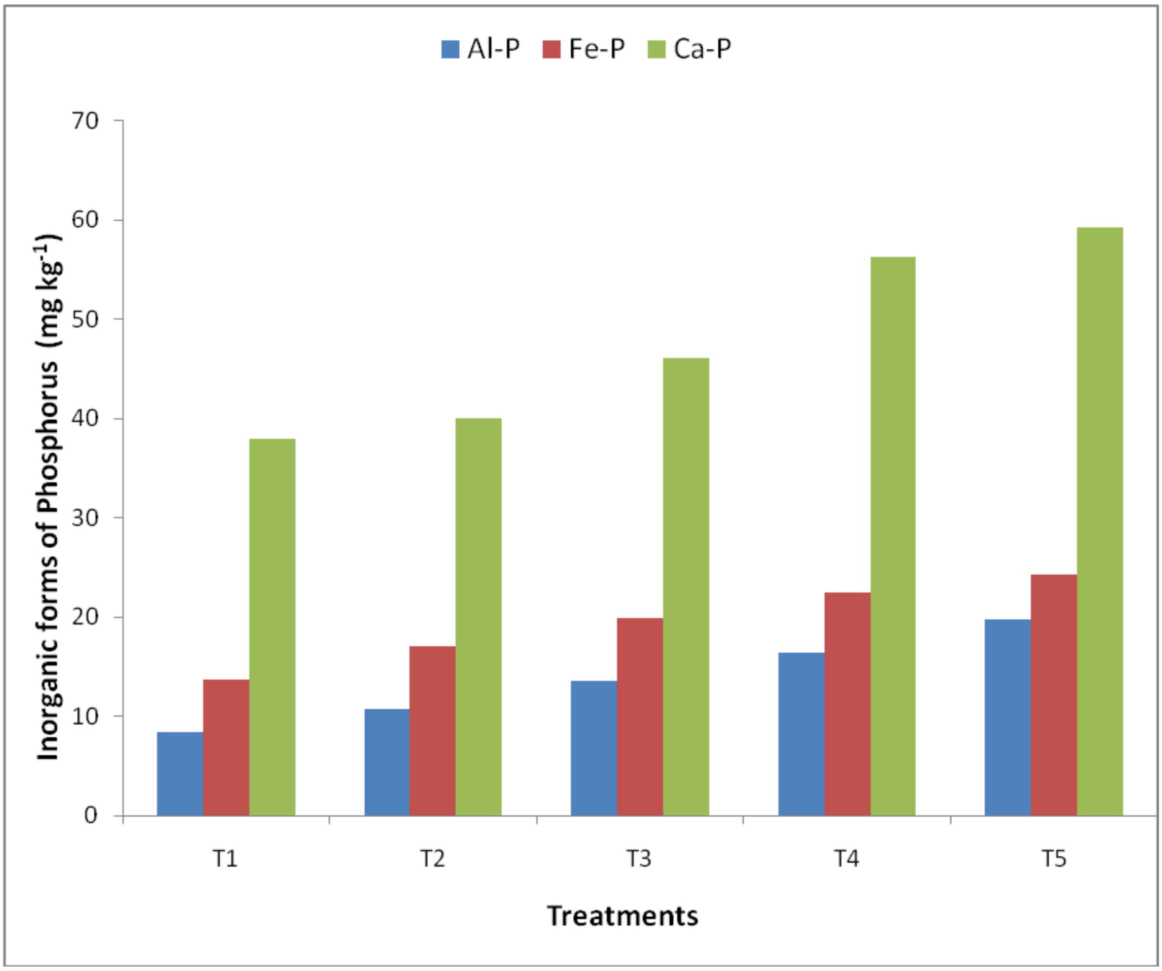


Fig. 1: Effect of various levels of phosphorus on Inorganic forms of Phosphorus (Al-P, Fe-P, Ca-P)

highest conc. i.e. 500 ppm it ranged from 317.90 to 323.68 mg kg^{-1} as well as the P desorption at 20 ppm conc. of P in equilibrium solution is ranged from 8.72 to 10.76 mg kg^{-1} and at highest conc. (500 ppm) it ranged from 475.97 to 479.72 mg kg^{-1}, respectively.

The table indicates that at higher concentration of P in equilibrium solution the P adsorption and desorption both increases in all treatments but, the control treatment (T_1) shows relatively higher P adsorption (105.20 mg kg^{-1}) and desorption (178.90 mg kg^{-1}) than rest of the treatments. The relatively higher P adsorption under control treatment may be due to high fixation potential due to long absence of P fertilization, which ultimately affects phosphorus availability in soil. As a result the desorption in the same treatment increased compared to other treatments. This indicates little effect of fertilization on P adsorption and desorption. Similar results were reported by Shailaja and Sahrawat (1990).

Table 5: Effect of various levels of phosphorus on P Adsorption (mg kg^{-1})

Conc. of P in equilibrium solution(ppm)	T_1	T_2	T_3	T_4	T_5
20	6.30	6.72	5.40	6.47	7.80
40	14.70	12.70	11.90	13.80	14.20
60	25.82	23.66	23.59	25.50	25.90
80	34.35	33.12	31.60	32.52	33.20
100	43.96	42.57	40.80	42.20	41.20
150	67.24	66.21	63.70	65.80	63.73
200	97.29	96.92	94.60	96.20	93.81
250	135.38	134.87	132.60	134.40	133.70
300	164.46	163.75	161.30	163.40	161.54
400	243.99	243.62	241.90	242.80	240.79
500	323.68	323.28	317.90	322.60	321.60
Mean	105.20	104.31	102.30	104.15	103.41

Table 6: Effect of various levels of phosphorus on P Desorption (mg kg^{-1})

Conc. of P in equilibrium solution(ppm)	T_1	T_2	T_3	T_4	T_5
20	10.76	10.54	10.29	9.85	8.72
40	30.52	29.83	29.77	29.66	27.66
60	49.86	49.71	49.59	49.44	46.24
80	69.79	68.79	68.66	68.62	65.46
100	88.68	88.55	88.48	88.31	83.66
150	138.56	138.42	138.39	137.87	131.05
200	188.47	188.27	187.69	187.26	179.21
250	238.29	237.56	237.32	236.47	228.70
300	287.64	285.38	279.54	279.66	277.79
400	385.57	379.51	378.72	378.99	376.71
500	479.72	479.29	478.53	478.71	475.97
Mean	178.90	177.80	177.00	176.80	172.83

Table 7: Effect of various levels of phosphorus on per cent P Adsorption (conc.)

Conc. of P in equilibrium solution(ppm)	T_1	T_2	T_3	T_4	T_5
20	31.50	33.60	27.00	32.35	39.00
40	36.75	31.75	29.75	34.50	35.50
60	43.03	39.43	39.32	42.50	43.17
80	42.94	41.40	39.50	40.65	41.50
100	43.96	42.57	40.80	42.20	41.20
150	44.83	44.14	42.47	43.87	42.49
200	48.65	48.46	47.30	48.10	46.91
250	54.15	53.95	53.04	53.76	53.48
300	54.82	54.58	53.77	54.47	53.85
400	61.00	60.91	60.48	60.70	60.20
500	64.74	64.66	63.58	64.52	64.32
Mean	43.86	42.95	41.42	43.13	43.47

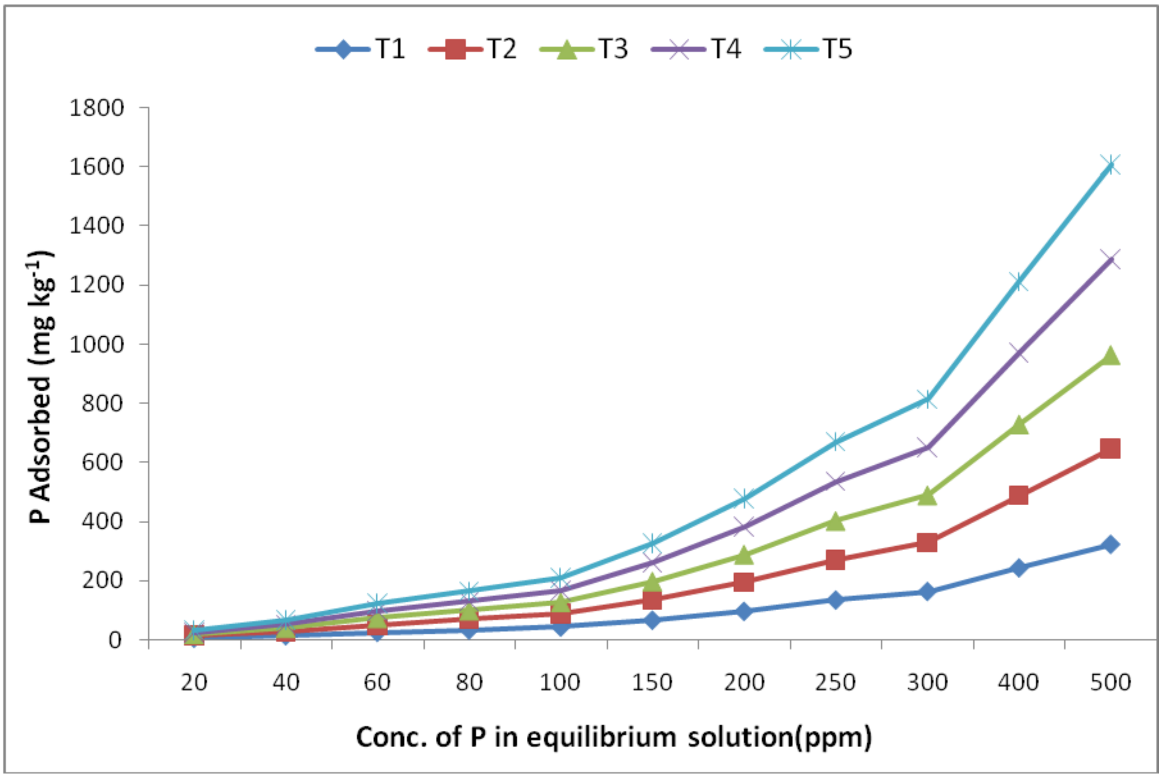


Fig. 2: Effect of various levels of phosphorus on P Adsorption (mg kg^{-1})

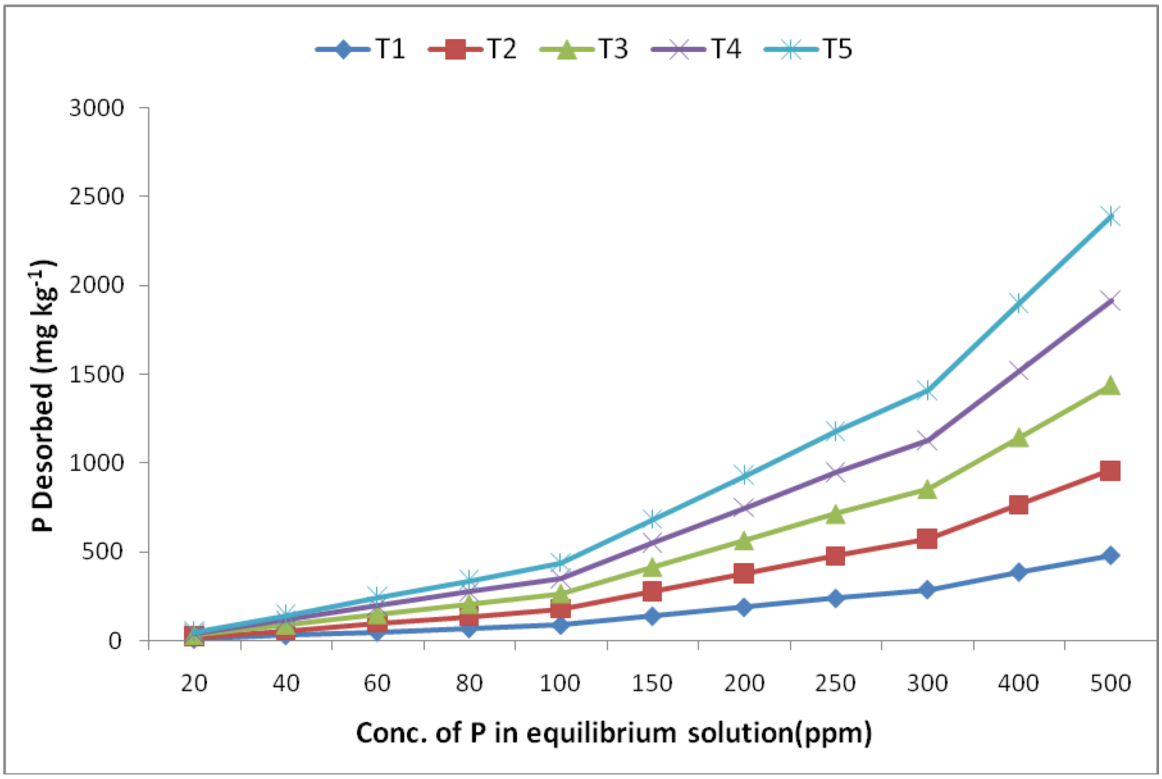


Fig. 3: Effect of various levels of phosphorus on P Desorption (mg kg^{-1})

Table 8: Effect of various levels of phosphorus on per cent P Desorption (conc.)

Conc. of P in equilibrium solution(ppm)	T_1	T_2	T_3	T_4	T_5
20	53.80	52.70	51.45	49.25	43.60
40	76.30	74.58	74.43	74.15	69.15
60	83.10	82.85	82.65	82.40	77.07
80	87.24	85.99	85.83	85.78	81.83
100	88.68	88.55	88.48	88.31	83.66
150	92.37	92.28	92.26	91.91	87.37
200	94.24	94.14	93.85	93.63	89.61
250	95.32	95.02	94.93	94.59	91.48
300	95.88	95.13	93.18	93.22	92.60
400	96.39	94.88	94.68	94.75	94.18
500	95.94	95.86	95.71	95.74	95.19
Mean	79.94	79.33	78.95	78.64	75.48

4.1.1 Buffering Capacity

The buffering capacity as defined by quantity-intensity factor suggest the change in the quantity factor per unit change in the intensity of P in the soil solution. This concept of quantity – intensity relationship has proved a useful guide in improving the understanding of P supply to the roots.

The data regarding buffering capacity has been depicted in table 9. It illustrates that the change in buffering capacity with respect of different phosphorus treatments was non-significant and therefore it is found that the respective soils have low phosphate adsorption capacity and that the phosphorus they adsorbed is easily desorbable. The data in respect of sorption characteristics as influenced by various levels of phosphorus is presentated in table 10. The Fig. 6(a), 6(b) shows that data fits well in langmuir isotherm.

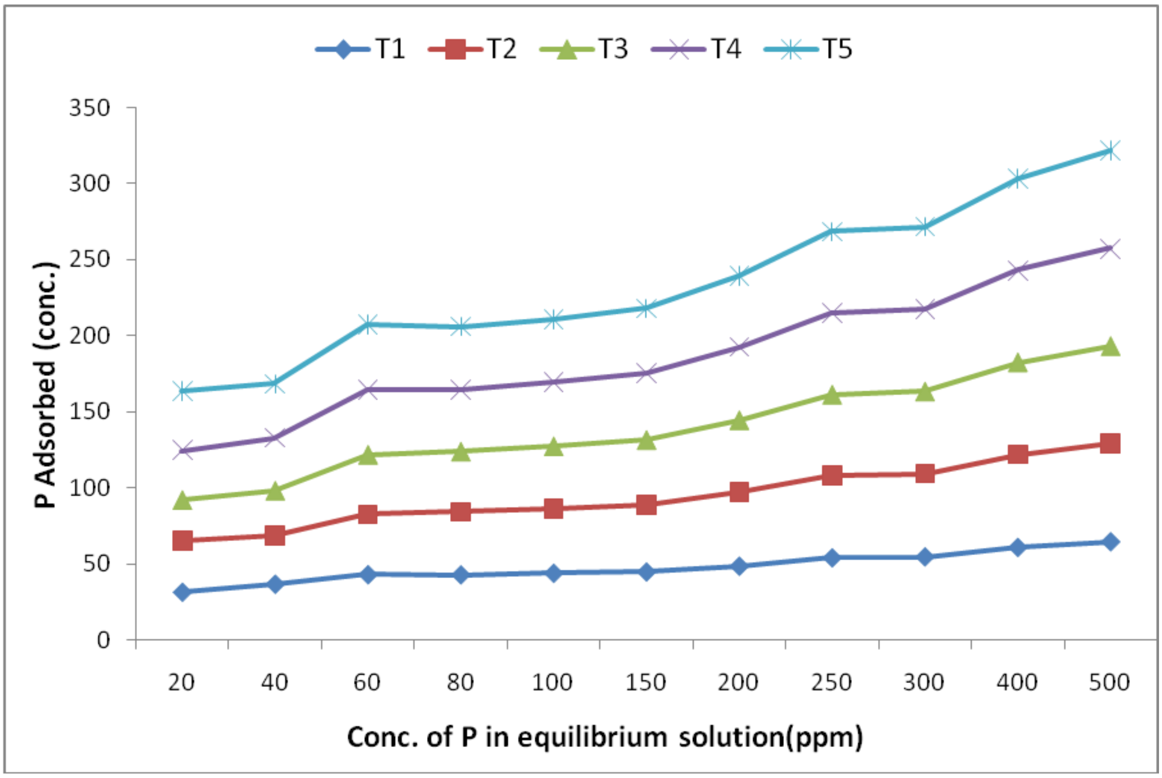


Fig. 4: Effect of various levels of phosphorus on per cent P Adsorption (conc.)

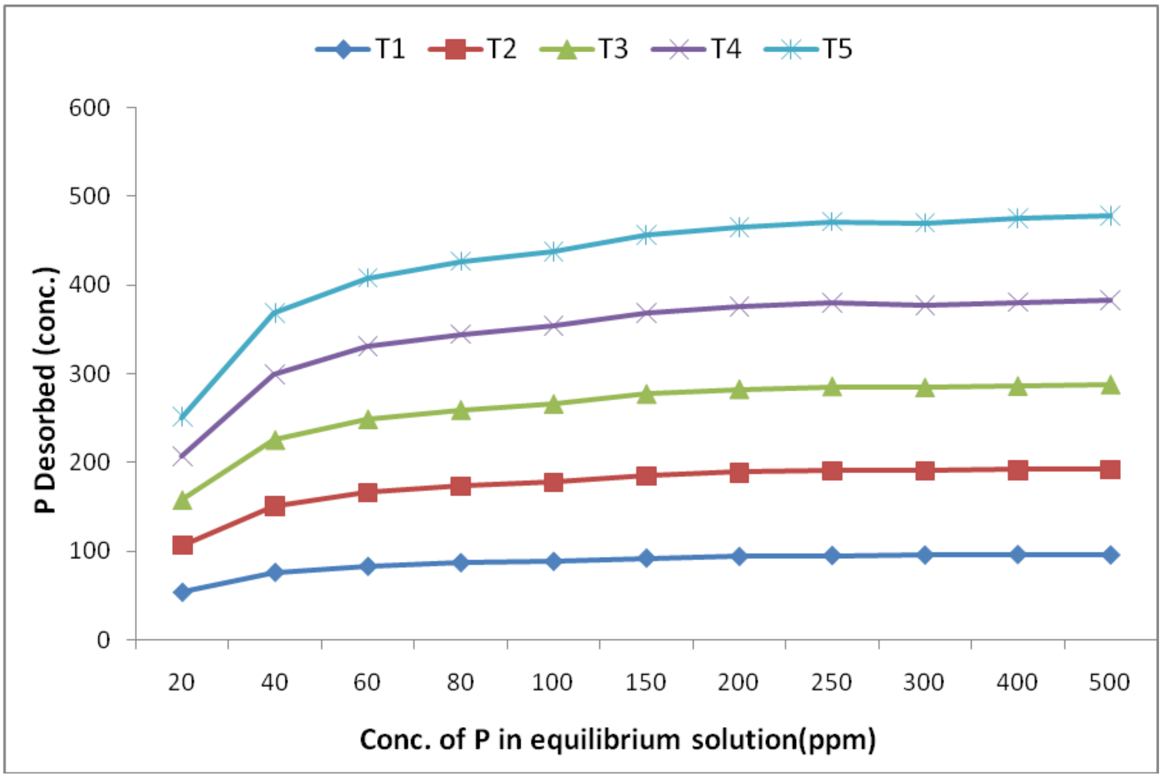


Fig. 5: Effect of various levels of phosphorus on per cent P Desorption (conc.)

Table 9: Effect of various levels of phosphorus on P Buffering Capacity

Treatments	Buffering Capacity (mg P kg^{-1})	R^2
T_1 - Absolute Control	28.867	0.865
T_2 - 30:45:30 kg N, P_2O_5 & K_2O ha^{-1}	28.951	0.864
T_3 - 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}	28.649	0.864
T_4 - 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}	28.801	0.862
T_5 - 30:90:30 kg N, P_2O_5& K_2O ha^{-1}	28.508	0.856

Table 10: Sorption characteristics as influenced by various levels of phosphorus

Treatments	a	b	R^2	Buffering Capacity (mg P kg^{-1})	P adsorption capacity (%)
T_1 - Absolute Control	1.71	39.29	0.917**	28.86	43.86
T_2 - 30:45:30 kg N, P_2O_5 & K_2O ha^{-1}	1.72	41.99	0.915**	28.95	42.95
T_3 - 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}	1.67	42.91	0.916**	28.64	41.42
T_4 - 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}	1.69	40.76	0.913**	28.80	43.13
T_5 - 30:90:30 kg N, P_2O_5& K_2O ha^{-1}	1.65	38.78	0.903**	28.50	43.47

4.3 Grain and Straw yield of soybean

The data regarding grain and straw yield of soybean has been compiled and presented in table 11 and Fig. 7.

4.3.1 Grain yield

The data in respect of grain yield of soybean was significantly influenced by various levels of phosphorus treatments. The maximum grain

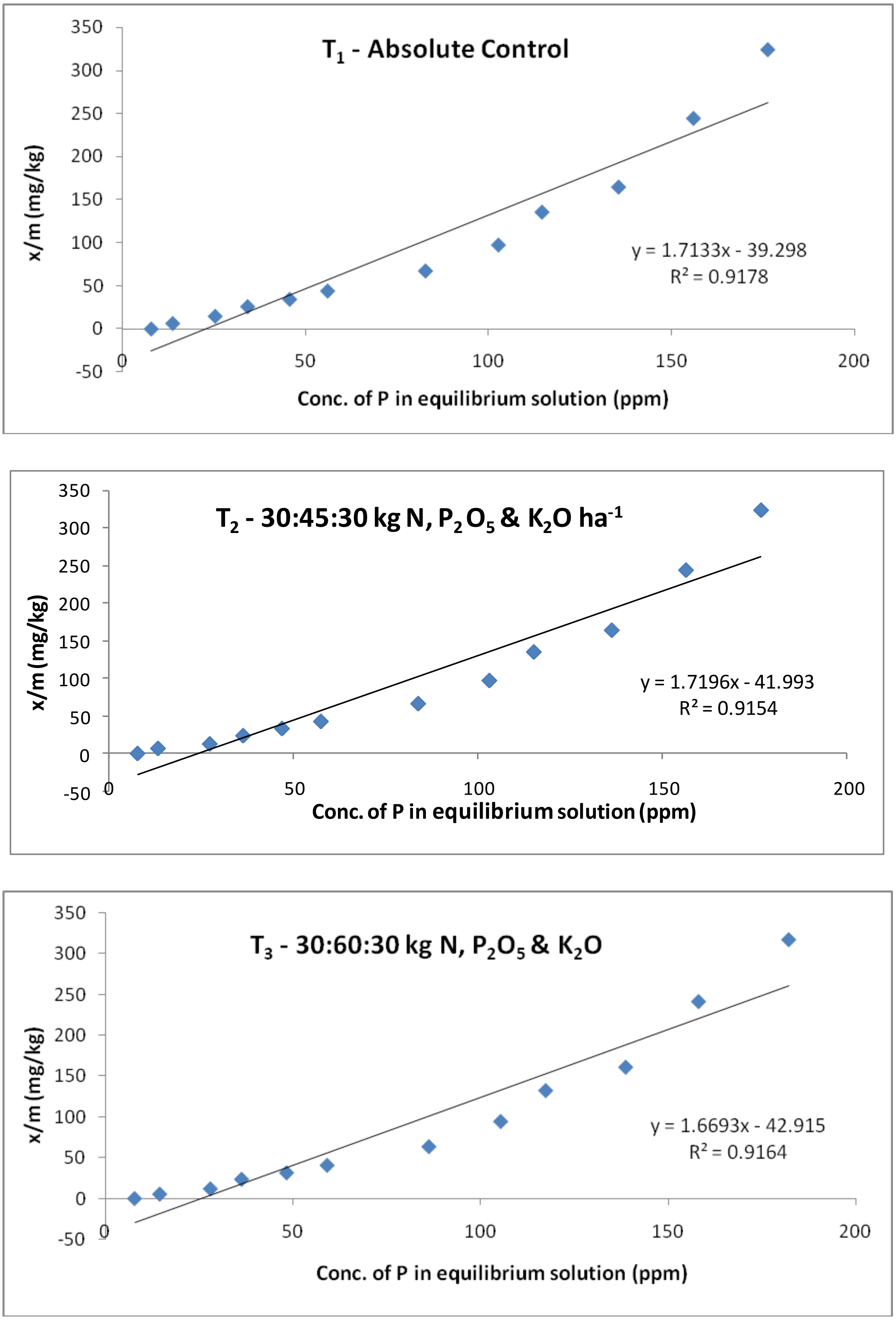
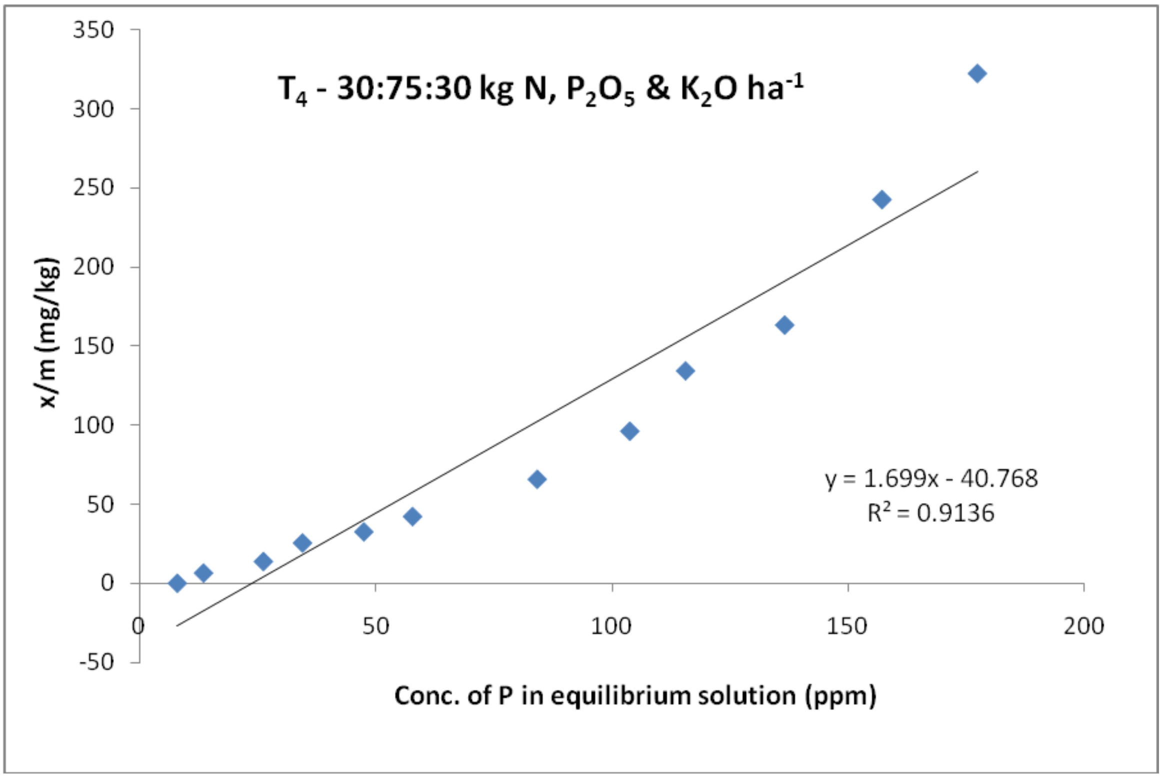


Fig. 6(a): Langmuir isotherm of sorbed P Vs conc. of P in equilibrium solution as influenced by various levels of phosphorus



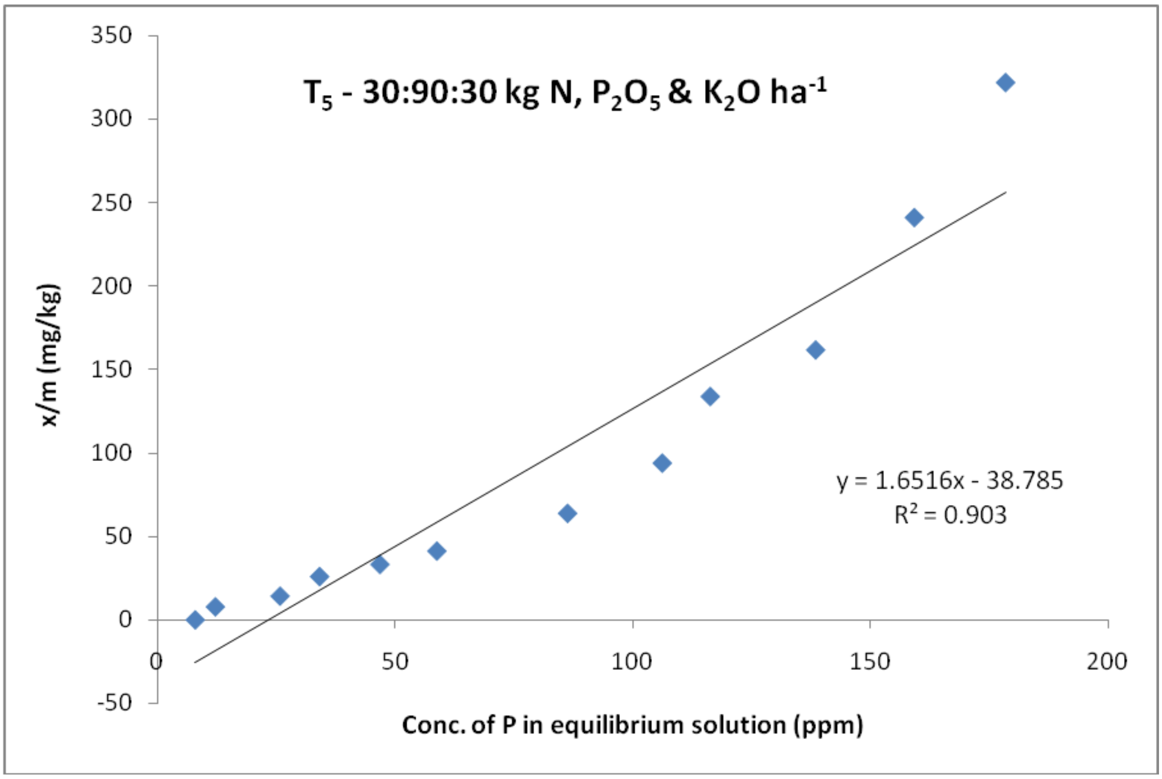


Fig. 6(b): Langmuir isotherm of sorbed P Vs conc. of P in equilibrium solution as influenced by various levels of phosphorus

yield (16.51 q ha^{-1}) was recorded with the application 90 kg P_2O_5 ha^{-1} which was significantly higher over lower levels of phosphorus application and at par with 60 and 75 kg P_2O_5 ha^{-1} along with recommended dose of N and K. The lowest grain yield (15.19 q ha^{-1}) was recorded in treatment T_1 i.e. control.

The results are in conformity with the findings of Narayana (2003), Botha *et al.* (2003) and Dhage *et al*. (2014).

4.3.2 Straw yield

The straw yield of soybean was significantly influenced by various levels of phosphorus. The yield of straw ranged between 20.58 to 26.96 q ha^{-1}. The maximum straw yield (26.96 q ha^{-1}) was recorded with the application 90 kg P_2O_5 ha^{-1}. However, the application of 75 kg P_2O_5 ha^{-1} along with recommended dose of N and K was found at par with the application of 90 kg P_2O_5 ha^{-1}. Higher grain and straw yield at higher levels of phosphorus might be due to increased chlorophyll content and photosynthetic rate and stable acid phosphatase activity to accumulate more dry matter after anthesis.

The results obtained during the study are closely related with the findings of Bahadur *et al.* (2012) and Khaswa *et al*. (2014) and Begum *et al.* (2015).

Table 11: Effect of various levels of phosphorus on yield of soybean

Treatments	Yield (qha^{-1})	
	Grain	Straw
T_1 - Absolute Control	15.19	20.58
T_2 - 30:45:30 kg N, P_2O_5 & K_2O ha^{-1}	15.63	23.73
T_3 - 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}	16.39	24.41
T_4 - 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}	16.40	26.33
T_5 - 30:90:30 kg N, P_2O_5& K_2O ha^{-1}	16.51	26.96
SE (m) ±	0.214	0.529
CD at 5 %	0.666	1.648

4.4 Nutrient content in soybean

The data regarding nitrogen, phosphorus and potassium concentration in grain and straw of soybean is placed in table 12 and depicted in Fig. 8.

4.4.1 Nitrogen concentration

The effect of various levels of phosphorus on nitrogen concentration in grain and straw was found to be non–significant. However, the highest nitrogen concentration in soybean grain (6.09%) and straw (1.34%) was recorded with the application of 90 kg P_2O_5 ha^{-1} (T_5) along with recommended dose N and K over remaining treatments.

4.4.2 Phosphorus concentration

The data indicate that the highest phosphorus content in soybean grain (0.66%) and straw (0.35%) was observed with the application of 90 kg P_2O_5 ha^{-1} (T_5) along with recommended dose of nitrogen and potassium. However it was at par with the application of 75 kg P_2O_5 ha^{-1} (T_4) along with recommended dose of N and K. The lowest uptake of phosphorus was recorded in control treatment. Phosphorus concentration in soybean grain and straw influenced significantly with the application of various levels of phosphorus. Phosphorus concentration was high in grain must be due to phosphorus taken up by the plant was utilized for grain formation.

The results are in accordance with the findings of Patel and Chandravanshi (1996), Bharambe and Tomar (2004).

4.4.3 Potassium concentration

The potassium concentration in grain was ranged from 0.71 to 0.79 and in straw it was from 1.58 to 1.65 per cent. The highest potassium concentration in soybean grain (0.79%) and straw (1.65%) was recorded with the application of 90 kg P_2O_5 ha^{-1} (T_5) over remaining treatments. While, the effect of various levels of phosphorus on potassium concentration in straw was found non-significant. Hence graphical representation has not been made.

Table 12: Effect of various levels of phosphorus on nutrient concentration of soybean

Treatments	Nutrient concentration (%)					
	Nitrogen		Phosphorus		Potassium	
	Grain	Straw	Grain	Straw	Grain	Straw
T_1 - Absolute Control	5.96	1.27	0.52	0.24	0.71	1.58
T_2 - 30:45:30 kg N, P_2O_5 & K_2O ha^{-1}	6.07	1.29	0.57	0.25	0.74	1.60
T_3 - 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}	6.06	1.30	0.61	0.29	0.76	1.62
T_4 - 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}	6.07	1.33	0.64	0.30	0.78	1.63
T_5 - 30:90:30 kg N, P_2O_5& K_2O ha^{-1}	6.09	1.34	0.66	0.35	0.79	1.65
SE (m) ±	0.076	0.056	0.012	0.020	0.256	0.303
CD at 5 %	NS	NS	0.04	0.06	NS	NS

4.5 Uptake of nutrients by soybean

The uptake studies were undertaken during the course of investigation. The data generated during the study in respect of uptake of nutrients is placed in table 13, 14, 15 and graphically represented Fig. 9, 10, 11.

4.5.1 Total uptake of nitrogen

The application of various levels phosphorus significantly influenced the uptake of nitrogen by soybean. The data in respect of nitrogen uptake by grain and straw of soybean as influenced by various levels of phosphorus is given in table 12 and depicted in Fig.8. The highest total nitrogen uptake (136.67 kg ha^{-1}) was recorded with application of 90 kg P_2O_5 ha^{-1} (T_5) and was statistically at par (134.56 kg ha^{-1}) with the application of 75 kg P_2O_5 ha^{-1} (T_4) along with recommended dose of N and K. The lowest total uptake of nitrogen (116.67 kg ha^{-1}) was noted by control treatment (T_1). The N uptake was increased with the increased phosphorus levels.

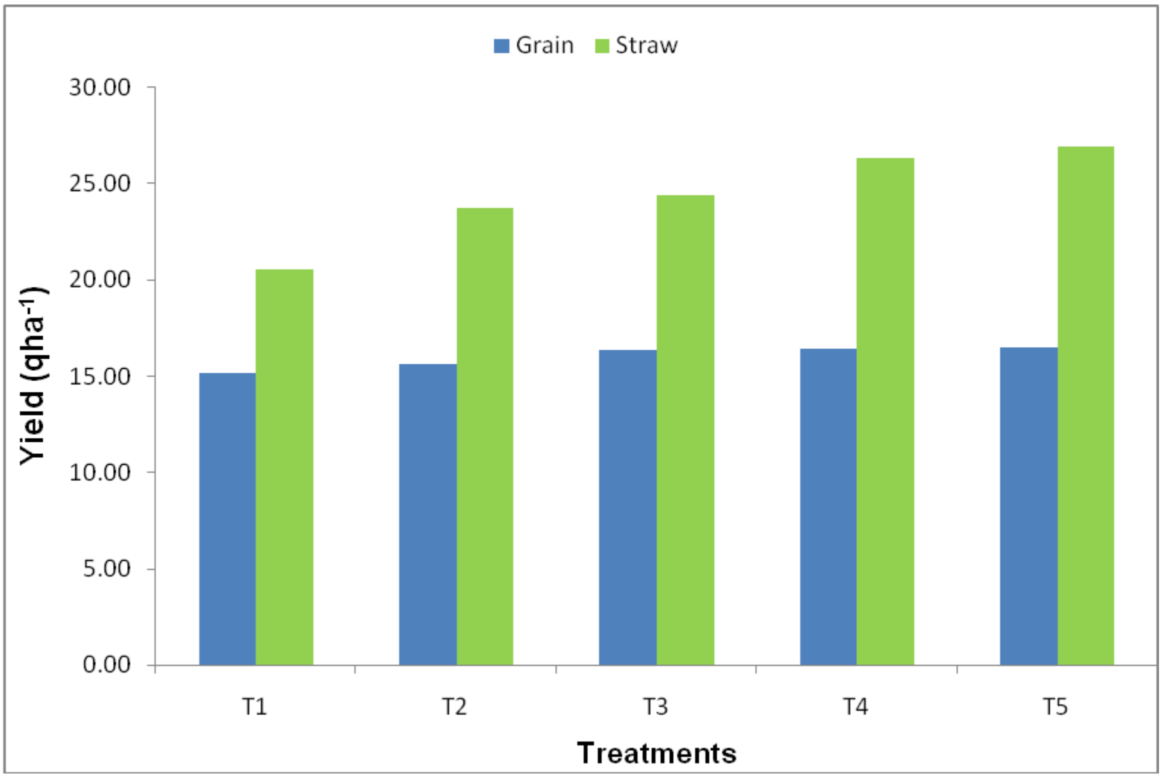


Fig. 7: Effect of various levels of phosphorus on grain and straw yield of soybean

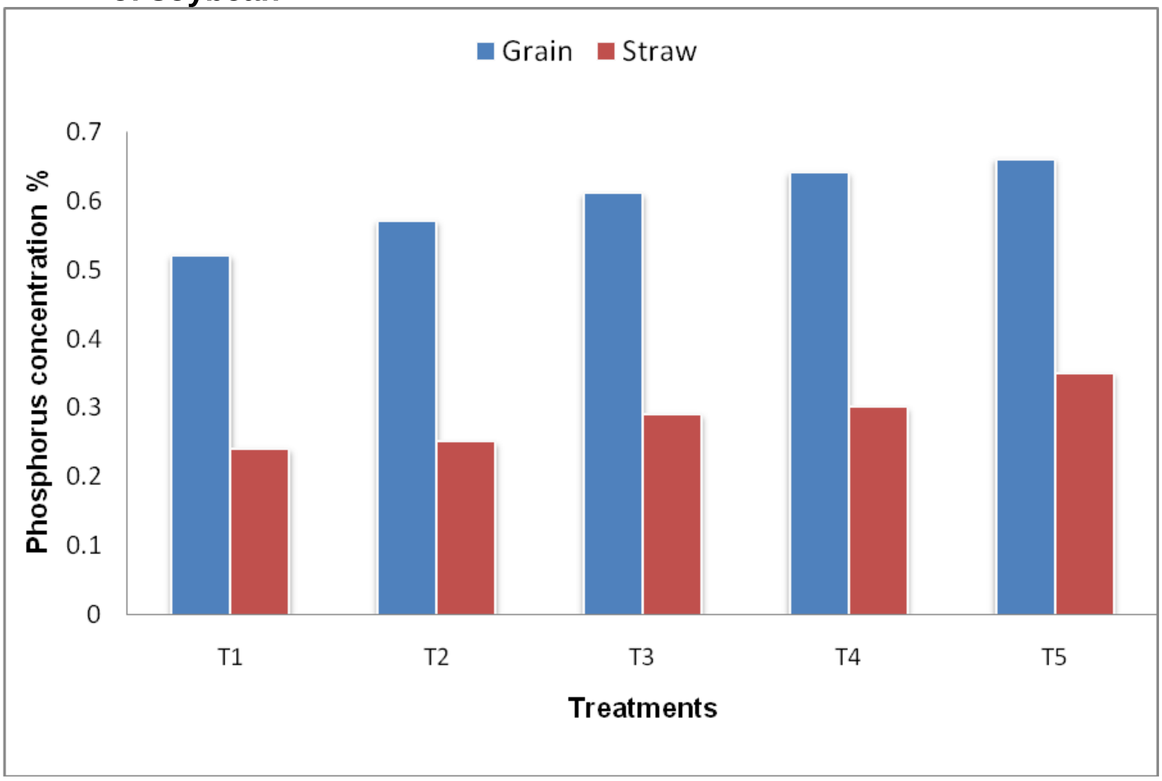


Fig. 8: Effect of various levels of phosphorus on phosphorus concentration of soybean

The results are in agreement with the findings of Nale (1996) and Chafle *et.al* (1999)**.**

Table 13: Effect of various levels of phosphorus on uptake of nitrogen by soybean

Treatments	Uptake of nitrogen (kg ha^{-1})		
	Grain	**Straw**	**Total**
T_1 - Absolute Control	90.53	26.14	116.67
T_2 - 30:45:30 kg N, P_2O_5 & K_2O ha^{-1}	94.87	30.61	125.48
T_3 - 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}	99.32	31.73	131.05
T_4 - 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}	99.55	35.01	134.56
T_5 - 30:90:30 kg N, P_2O_5& K_2O ha^{-1}	100.54	36.13	136.67
SE (m) ±	0.344	1.182	1.054
CD at 5 %	1.06	3.64	3.25

4.5.2 Total uptake of phosphorus

The data regarding uptake of phosphorus by grain and straw of soybean as influenced by various levels of phosphorus is placed in table 13 and depicted in Fig. 9. It shows the application of various levels of phosphorus significantly increased the uptake of phosphorus by soybean. The highest phosphorus uptake (20.33 kg ha^{-1}) was recorded with application of 90 kg P_2O_5 ha^{-1}(T_5) which was at par with the application of 75 kg P_2O_5 ha^{-1}(T_4) along with recommended dose N and K. The lowest total uptake of P was recorded in control treatment (T_1). In general, the uptake of nutrient with the application of various levels of phosphorus along with recommended dose N and K was in the order of 90 kg P_2O_5 > 75 kg P_2O_5 > 60 kg P_2O_5 > 45 kg > 0 kg P_2O_5. The increasing level of phosphorus application has significant influence on the uptake of phosphorus.

The similar results were noted by Bharambe and Tomar (2004), Sharma *et al*. (2011).

Table 14: Effect of various levels of phosphorus on uptake of phosphorus by soybean

Treatments	Uptake of Phosphorus (kg ha^{-1})		
	Grain	Straw	Total
T_1 - Absolute Control	7.90	4.94	12.84
T_2 - 30:45:30 kg N, P_2O_5 & K_2O ha^{-1}	8.90	5.93	14.83
T_3 - 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}	10.00	7.07	17.07
T_4 - 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}	10.50	7.89	18.39
T_5 - 30:90:30 kg N, P_2O_5& K_2O Pa^{-1}	10.89	9.44	20.33
SE (m) ±	0.227	0.505	0.634
CD at 5 %	0.70	1.56	1.96

4.5.3 Total Uptake of Potassium

The application of various levels of phosphorus significantly influenced the potassium uptake by soybean. The data in respect of uptake of phosphorus by grain and straw of soybean as influenced by various levels of phosphorus is placed in table 14 and depicted in Fig.10. The highest potassium uptake (57.52 kg ha^{-1}) was recorded with the application of 90 kg P_2O_5 ha^{-1} (T_5) and was at par with the 75 kg P_2O_5 ha^{-1}(T_4) level. The lowest uptake of potassium (43.29 kg ha^{-1}) was recorded in control treatment (T_1).The increasing levels of phosphorus also increase the concentration and uptake of K by grains and straw of soybean. This might be due to response of crops to incremental levels of nutrients.

The results are in agreement with the findings of Dubey (1997), Chaturvedi and Chandel (2005).

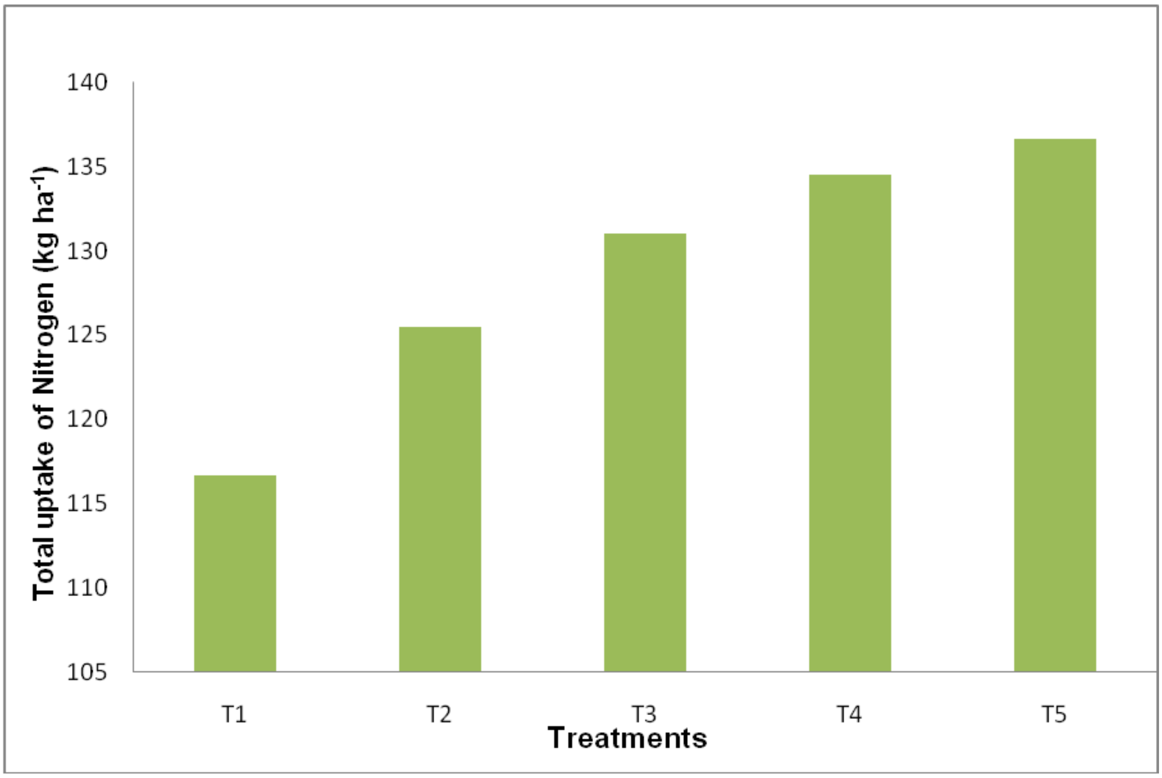


Fig. 9: Effect of various levels of phosphorus on total uptake of nitrogen by soybean

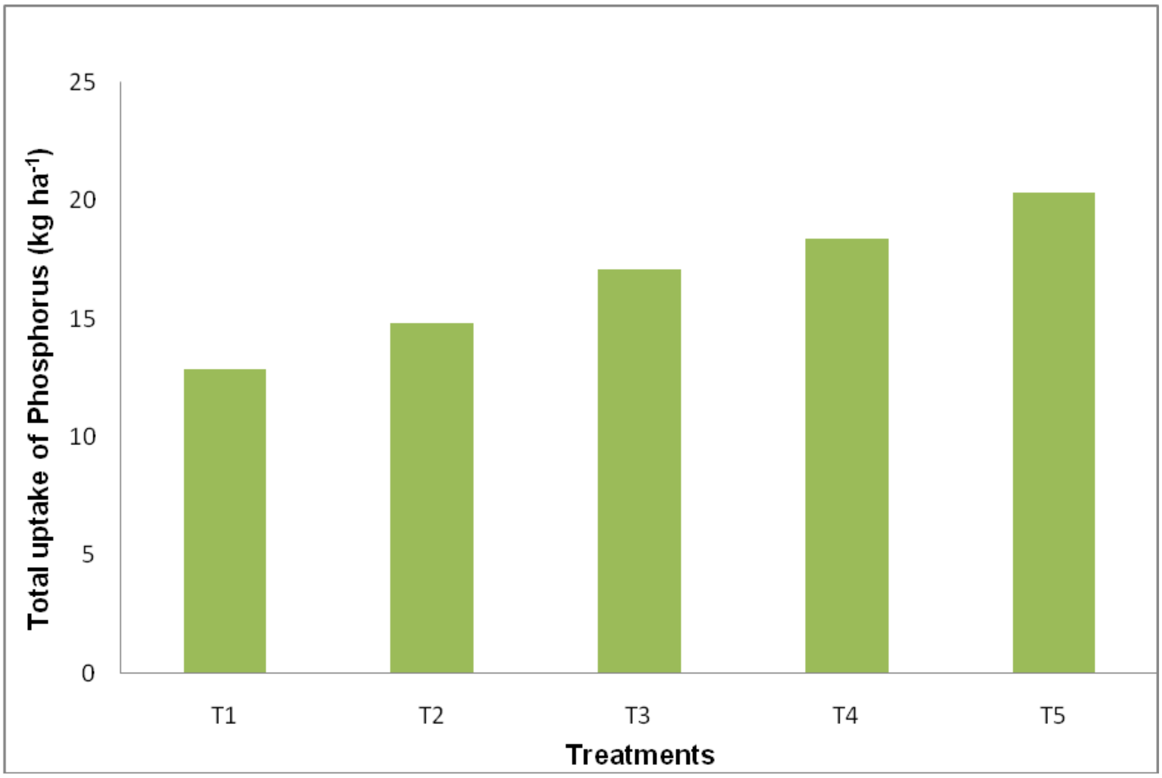


Fig. 10: Effect of various levels of phosphorus on total uptake of phosphorus by soybean

Table 15: Effect of various levels of phosphorus on uptake of potassium by soybean

Treatments	Uptake of potassium (kg ha^{-1})		
	Grain	Straw	Total
T_1 - Absolute Control	10.78	32.51	43.29
T_2 - 30:45:30 kg N, P_2O_5 & K_2O ha^{-1}	11.56	37.96	49.52
T_3 - 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}	12.45	39.54	51.99
T_4 - 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}	12.79	42.92	55.71
T_5 - 30:90:30 kg N, P_2O_5& K_2O ha^{-1}	13.04	44.48	57.52
SE (m) ±	0.176	0.545	0.643
CD at 5 %	0.54	1.68	1.98

4.6 Effect of various levels of phosphorus on chemical properties of soil

4.6.1 Soil pH (1:2.5)

The negative logarithm of hydrogen ion activity which indicates the acidity or alkaline nature of soil is usually expressed as pH value. The data regarding soil pH presented in Table 16. The results indicated that the pH of soil ranged from 8.38 to 8.41, indicating that soil was moderately alkaline in reaction. The effect of various levels of phosphorus on pH of soil after harvest of soybean was found non-significant. The results are in close conformity with the findings of Gattani *et al*. (1976).

4.6.2 Electrical conductivity (dSm^{-1})

The electrical conductivity is a measure of soluble salt concentration in soil. Higher amount of salts in the soil restrict the nutrient uptake and thus affect the plant growth. The data in respect of electrical conductivity of soil was found to be non-significant. The electrical conductivity was ranged from 0.23 to 0.26 dS m^{-1}. The marginal increase in electrical conductivity of soil might be due to accumulation of soluble salts. Similar result was also reported by Dwivedi *et al.* (2015).

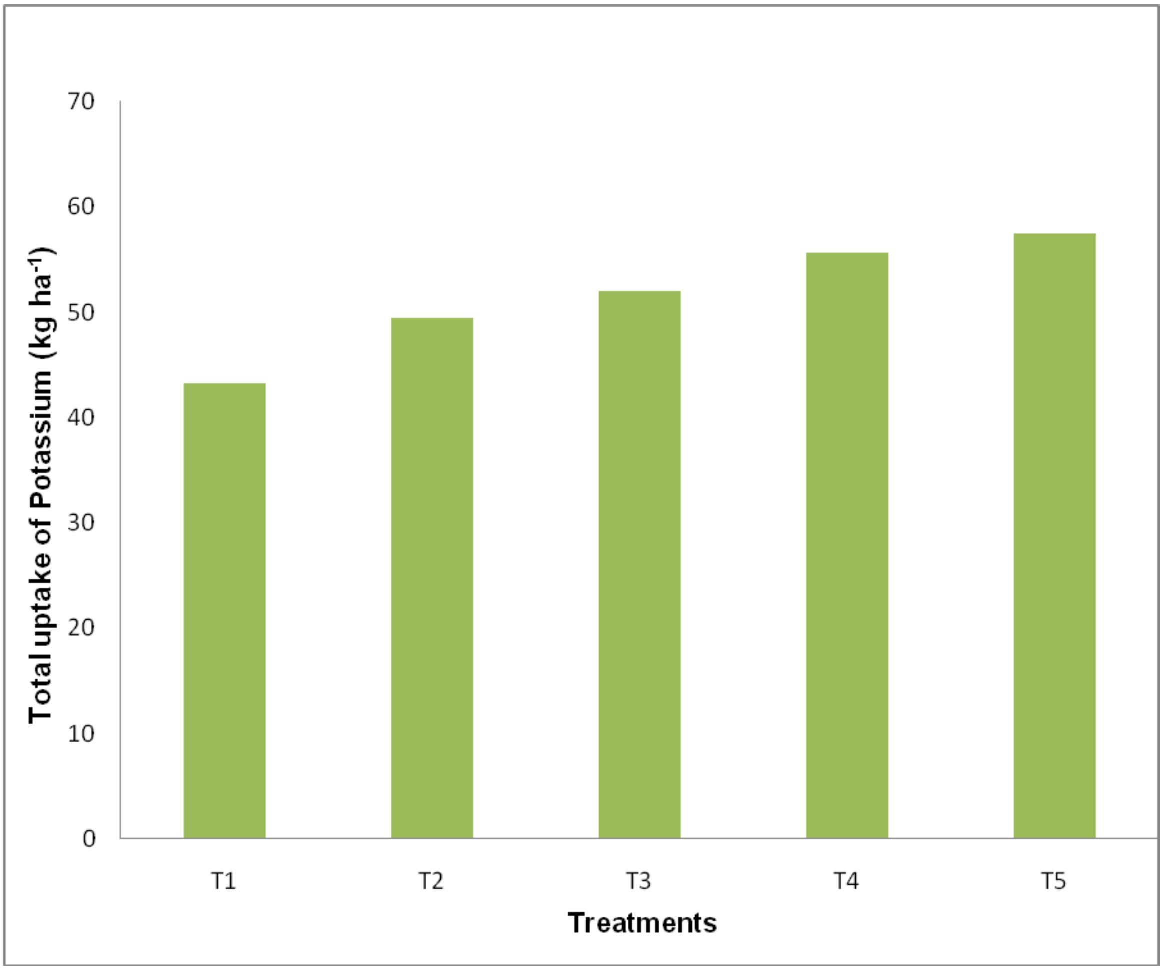


Fig. 11: Effect of various levels of phosphorus on total uptake of potassium by soybean

4.6.3 Organic carbon

Soil organic carbon is important as it determines agro-ecosystem functions, influencing soil fertility, water holding capacity and other soil parameters which ultimately stimulate crop productivity. The data pertaining to the organic carbon content of soil as influenced by various phosphorus treatments placed in table 16. The results showed that the organic carbon was non-significant and it ranged from 5.93 to 6.10 g kg^{-1}. The higher organic carbon (6.10 g kg^{-1}) was recorded with the application 90 kg P_2O_5 ha^{-1} (T_5).

4.6.4 Calcium carbonate

The data regarding calcium carbonate indicated in table 16. The results showed that calcium carbonate was ranged from 6.34% to 6.45% with various treatments. There was non-significant effect of various levels of phosphorus treatments on calcium carbonate content of soil.

Table 16: Effect of various levels of phosphorus on soil chemical properties

Treatments	Soil chemical properties			
	pH (1:2.5)	**EC (dSm^{-1})**	**OC (g kg^{-1})**	**$CaCO_3$ (%)**
T_1 - Absolute Control	8.38	0.23	5.93	6.34
T_2 - 30:45:30 kg N, P_2O_5 & K_2O ha^{-1}	8.39	0.24	5.98	6.36
T_3 - 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}	8.39	0.24	6.02	6.41
T_4 - 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}	8.41	0.25	6.06	6.42
T_5 - 30:90:30 kg N, P_2O_5& K_2O ha^{-1}	8.41	0.26	6.10	6.45
SE (m) ±	0.009	0.008	0.038	0.366
CD at 5%	NS	NS	NS	NS

4.6.5 Available nitrogen

The data regarding available nitrogen status of soil has been presented in table 17 and Fig. 12. The results showed that the soil available nitrogen ranged from 149 to 154 kg ha^{-1}. The available nitrogen was numerically increased with the application of 90 kg P_2O_5 ha^{-1} followed by 75, 60, 45 kg P_2O_5 ha^{-1} along with recommended dose of nitrogen and potassium. The results pertaining to available nitrogen status of soil was non-significant. The results are in agreement with the findings of Yadav (1998) and Mathew *et al.* (2018).

4.6.6 Available phosphorus

The data concerning to available phosphorus status is integrated in table 17 and depicted in Fig. 12. The results indicated that there was significant effect of various levels of phosphorus treatments. The available phosphorous content of soil ranged from 10.92 to 17.62 kg ha^{-1}. Significantly the highest available phosphorus (17.62 kg ha^{-1}) was recorded with the treatment where 90 kg P_2O_5 ha^{-1} was applied and at par with application of 75 kg P_2O_5 ha^{-1} (15.73 kg ha^{-1}) and 60 kg (13.81 kg ha^{-1}) along with recommended dose of N and K. The increment in available phosphorus might be due to additional supply of phosphorus with increasing levels. Dwivedi *et al*. (1989) also observed the gradual increase in phosphorous availability with increasing level of phosphorus.

Similar results were also reported by Dwivedi *et al*. (1989), Yadav *et al.* (2010) and Amba *et al.* (2011).

4.6.7 Available potassium

The data pertaining to available potassium status of soil is placed in table 17 and depicted in Fig. 12. The application of various levels of phosphorus has non- significant effect on available K. The available potassium content in soil was ranged from 384 to 391 kg ha^{-1} as influenced by various levels of phosphorus application. Progressive increase in the available potassium was noticed with each level of phosphorus, but the numerical increment was noticed. The similar findings were also quoted by Meena *et al.* (2013).

Table 17: Effect of various levels of phosphorus on available nutrient

Treatments	Available nutrient (kg ha^{-1})		
	N	P	K
T_1 - Absolute Control	149	10.92	384
T_2 - 30:45:30 kg N, P_2O_5 & K_2O ha^{-1}	152	12.34	387
T_3 - 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}	152	13.81	389
T_4 - 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}	153	15.73	389
T_5 - 30:90:30 kg N, P_2O_5& K_2O ha^{-1}	154	17.62	391
SE (m) ±	4.23	1.28	15.22
CD at 5 %	NS	4.017	NS

4.7 Number and dry weight of nodules of soybean at 60 DAS

The results attained in respect of number and dry weight of nodules as influenced by various levels phosphorus are placed in table 18 and graphically represented in Fig. 13, 14.

4.7.1 Effect on number of root nodules

The table shows that the number of root nodules was significantly influenced with the increasing levels of phosphorus along with recommended dose of N and K over control (T_1). The significant effect of phosphorus on number of root nodules $plant^{-1}$ was noted. The highest root nodules (24.5 $plant^{-1}$) was observed with the application of 90 kg P_2O_5 ha^{-1}(T_5) along with recommended dose of N and K. However, all the treatments except control were found at par. The phosphorus application helps in formation of root nodules because nodulation is energy driven process and phosphorus provides the energy required for the nodule formation which ultimately enhances the potential of N_2 fixation.

The results are in accordance with the findings of Goswami *et al.* (1999), Jain and Trivedi (2005), Kakad (2005) and Asghar *et al.* (2006).

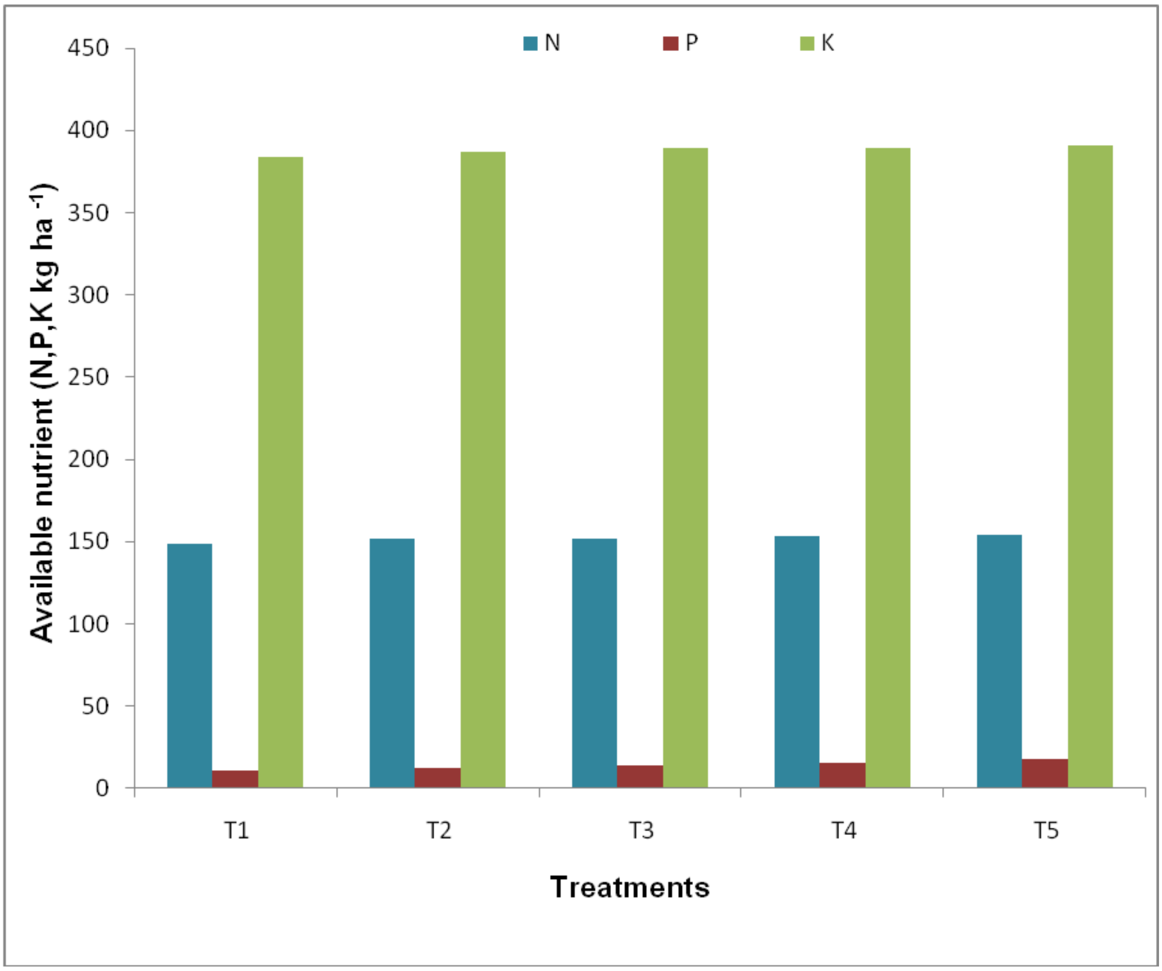


Fig. 12: Effect of various levels of phosphorus on available nutrients

4.7.2 Effect on dry weight of nodules

The dry weight of root nodules was significantly increased with varying levels of phosphorus application. The highest dry weight of nodules plant^{-1} (0.35 mg plant^{-1}) was noted with the application of 90 kg P_2O_5 ha^{-1} at 60 DAS, whereas the treatment T_4 i.e. application of 75 kg P_2O_5 ha^{-1} along with recommended dose of N and K was found at par with the application of 90 kg P_2O_5 ha^{-1}. Increase in dry weight of nodules might be due to more number of nodules plant^{-1}.

Similar results were also reported by Prasad *et al.* (1993), Singh and Pareek (2003) and Abbasi *et al*. (2008)

Table 18: Effect of various levels of phosphorus on nodulation of soybean

Treatments	Nodulation at 60 DAS	
	Number of nodules (plant^{-1})	Dry weight of nodules (mg plant^{-1})
T_1 - Absolute Control	21.25	0.260
T_2 - 30:45:30 kg N, P_2O_5 & K_2O ha^{-1}	23.50	0.285
T_3 - 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}	23.75	0.324
T_4 - 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}	24.25	0.337
T_5 - 30:90:30 kg N, P_2O_5& K_2O ha^{-1}	24.50	0.350
SE (m) ±	0.379	0.005
CD at 5 %	1.181	0.014

4.8 Root length and volume at 60 DAS

Data regarding root length and volume has been placed in table 19 and depicted in Fig. 15, 16. The results showed that the various levels of phosphorus treatments significantly influenced the root length and volume of soybean. Significantly higher root length (181.5 cm) and volume

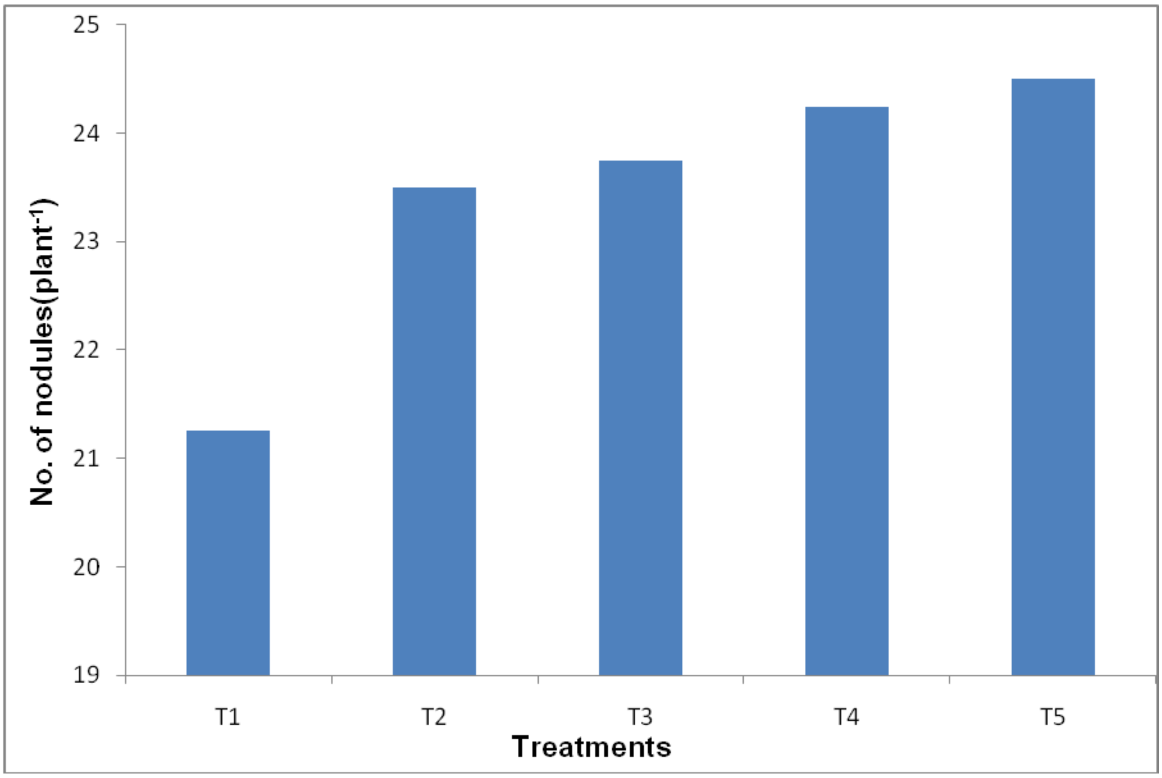


Fig. 13: Effect of various levels of phosphorus on no. of nodules of soybean

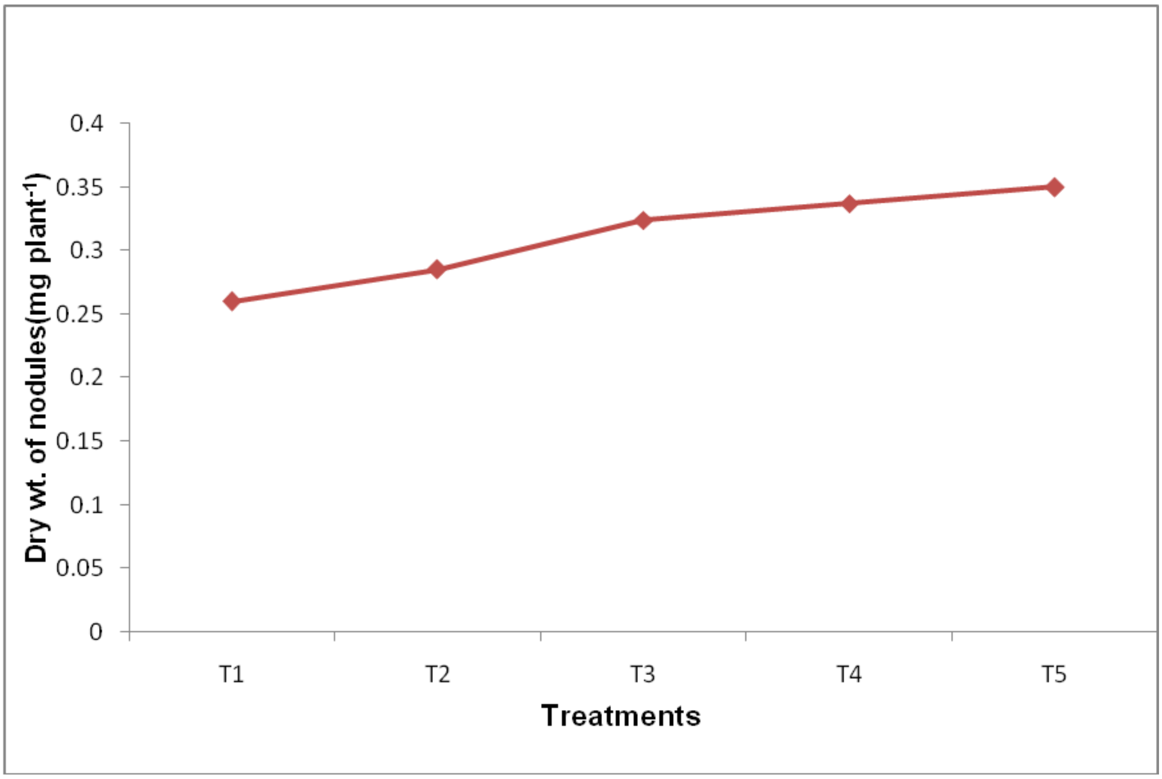


Fig. 14: Effect of various levels of phosphorus on dry wt. of nodules of soybean

($0.081 cm^3$) was found at 90 kg P_2O_5 (T_5) followed by 75, 60, 45, 30 kg P_2O_5 i.e. T_4, T_3, T_2. The lowest root length and volume was found in control (T_1).

Increase in root length and volume at higher levels of phosphorus might be due to the plants grown with inorganic P allocated more biomass to roots than shoots, resulting in a higher root to shoot ratio. Increasing P concentration also helped to increase the accumulation of P in all plant parts, but predominantly in shoots, whereas further increasing the concentration increased the accumulation primarily in roots.

The results are in close conformity with the findings of Jin *et al.* (2005), Darwesh *et al.* (2013), Zou *et al.* (2015) and Spandana *et al.* (2016).

Table 19: Effect of various levels of phosphorus on root length and volume of soybean

Treatments	Root study at 60 DAS		
	No. of root interception points	**Root length (cm)**	**Root volume (cm^3)**
T_1 - Absolute Control	145	113.9	0.047
T_2 - 30:45:30 kg N, P_2O_5 & K_2O ha^{-1}	171	134.4	0.056
T_3 - 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}	216	169.7	0.069
T_4 - 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}	224	176.0	0.073
T_5 - 30:90:30 kg N, P_2O_5 & K_2O ha^{-1}	231	181.5	0.081
SE (m) ±	0.689	0.395	0.001
CD at 5 %	2.147	1.23	0.003

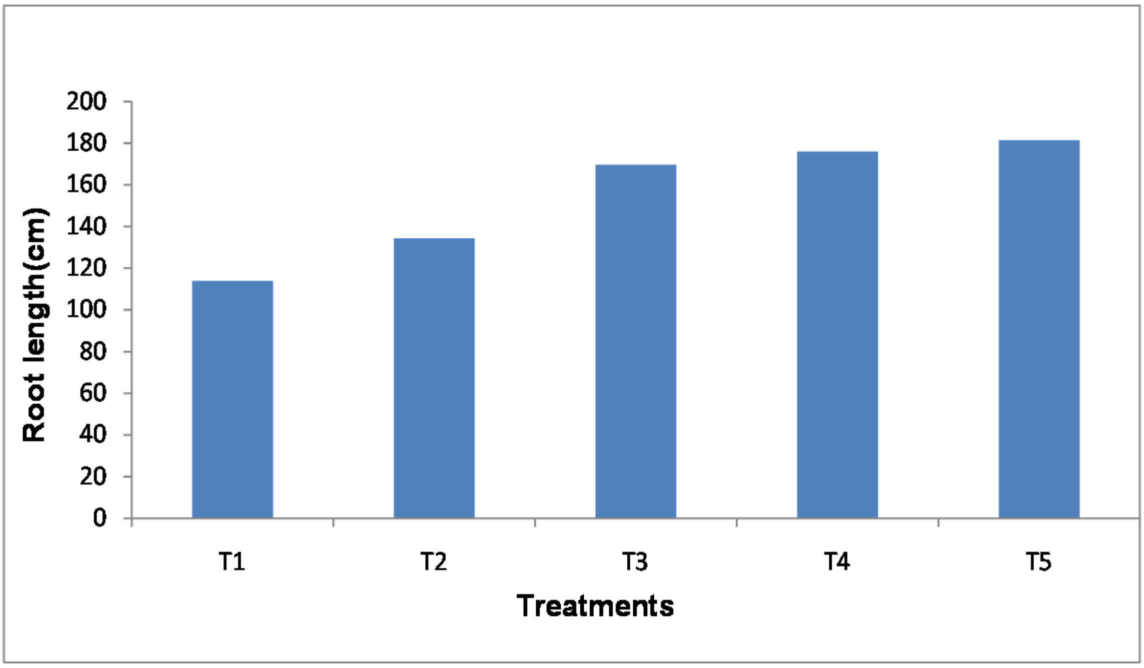


Fig. 15: Effect of various levels of phosphorus on root length of soybean

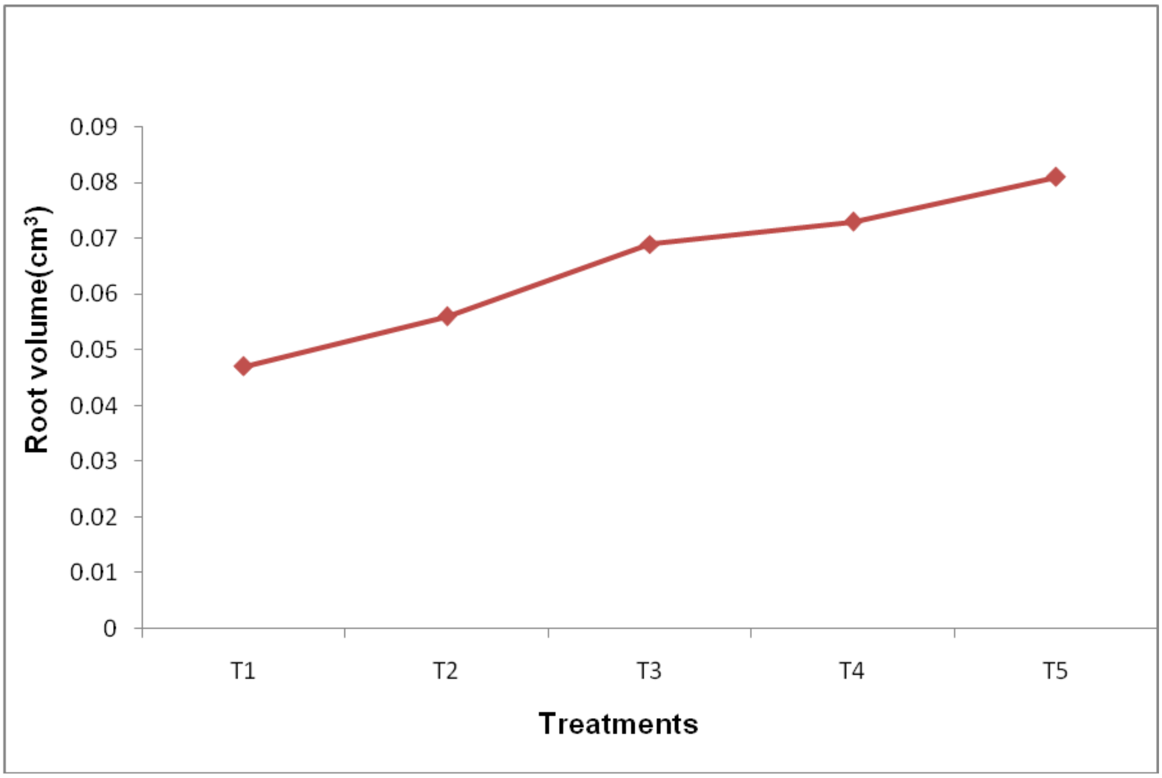


Fig. 16: Effect of various levels of phosphorus on root volume of soybean

CHAPTER V

SUMMARY AND CONCLUSIONS

The present investigation entitled "Phosphorus adsorption - desorption as influenced by various levels of phosphorus under soybean grown in Vertisols" was conducted at Research Farm, Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during *kharif* season 2019-20.

The experiment was laid out in randomized block design with five treatments randomized in four replications. The soil of experimental site was Vertisol, which was low in nitrogen, low in available phosphorus and high in potassium.

The treatment wise surface soil sample (0-20 cm) were collected and analysed to evaluate the various soil properties. The soil samples were analysed for inorganic forms of phosphorus (Fe-P, Al-P and Ca-P) and phosphorus adsorption- desorption and other chemical properties of soil. The plant samples were analysed for nutrient uptake, root and nodulation study. The soybean grain and straw yield was also recorded. The results obtained from the present investigation are summarized in this chapter and the relevant conclusions are drawn.

5.1 Adsorption–desorption of phosphorus

Among the various treatments the amalgamation of phosphorus along with recommended dose of N and K, the adsorption and desorption were increased at higher concentration of phosphorus in equilibrium solution. Similarly, the control treatment (T_1) shows higher P adsorption (105.20 mg kg^{-1}) and desorption (178.90 mg kg^{-1}) than rest of the treatments indicating little contribution of applied fertilizer in adsorption and desorption of phosphorus.

5.1.1 P Buffering capacity

The buffering capacity has shown significant difference in respect of P adsorption and desorption. But the change in buffering capacity with respect of different levels of phosphorus was non-significant.

5.2 Inorganic forms of phosphorus

The different levels of phosphorus significantly influenced the inorganic forms of phosphorus. The Ca-P was higher (59.28 mg kg^{-1}) than Fe-P (24.32 mg kg^{-1}) and Al-P (19.77 mg kg^{-1}).

5.3 Yield of soybean

Among the various treatments, the significantly higher soybean grain yield (16.51 q ha^{-1}) was recorded with the application of 30:90:30 kg N, P_2O_5 & K_2O ha^{-1}(T_5) however, it was at par with 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}(T_4) and 30:60:30 kg N, P_2O_5 & K_2O ha^{-1} (T_3).

Similarly, the higher soybean straw yield (26.96 q ha^{-1}) was observed with the application of 30:90:30 kg N, P_2O_5 & K_2O ha^{-1}(T_5) though, it was at par with and 30:75:30 kg N, P_2O_5 & K_2O ha^{-1}(T_4) and 30:60:30 kg N, P_2O_5 & K_2O ha^{-1} (T_3).

5.4 Concentration of nutrient

The application of different levels of phosphorus did not shown significant influence on nitrogen and potassium content but it has significantly influenced the phosphorus content. However, the maximum nitrogen (6.09%), phosphorus (0.66%) and potassium (0.79%) concentration were recorded with the application of 30: 90:30 kg N, P_2O_5 & K_2O ha^{-1} (T_5).

5.5 Total uptake of nutrients

The total uptake of nutrients by soybean was significantly influenced by different phosphorus based treatments over control. However, uptake of nitrogen (136.67 kg ha^{-1}) phosphorus (20.33 kg ha^{-1}) and potassium (57.52 kg ha^{-1}) were significantly highest with the application of 30:90:30 kg N, P_2O_5 & K_2O ha^{-1} (T_5) over the remaining treatments.

5.6 Soil chemical properties

The pH, EC, OC and $CaCO_3$ were numerically increased with the application of 30:90:30 kg N, P_2O_5 & K_2O ha^{-1} (T_5) over all the treatments. However, application of phosphorus has not shown any significant change in chemical properties of soil.

5.6.1 Available nitrogen

Available nitrogen status of soil was not influenced with various levels of phosphorus. The highest available nitrogen (154 kg ha^{-1}) was recorded with application of 30:90:30 kg N, P_2O_5 & K_2O ha^{-1} (T_5) followed by 75, 60, 45 kg P_2O_5 ha^{-1}, while it has non-significant effect among the treatments.

5.6.2 Available phosphorus

The different levels of phosphorus significantly increased the status of available P. Significantly highest available P (17.62 kg ha^{-1}) was recorded with the application of 30:90:30 kg N, P_2O_5 & K_2O ha^{-1}. However, it was at par with 30:75:30 kg N, P_2O_5 & K_2O ha^{-1} and 30:60:30 kg N, P_2O_5 & K_2O ha^{-1}.

5.6.3 Available potassium

The effect of various levels of phosphorus treatments on available potassium was found non-significant. The highest available potassium (391 kg ha^{-1}) was recorded with application of 30:90:30 kg N, P_2O_5 & K_2O ha^{-1} (T_5) followed by 30:75:30 kg N, P_2O_5 & K_2O ha^{-1} (T_4), 30:60:30 kg N, P_2O_5 & K_2O ha^{-1} (T_3), 30:45:30 kg N, P_2O_5 & K_2O ha^{-1} (T_2) and absolute control(T_1). However, levels of phosphorus have not shown any prominent increase in available potassium.

5.7 Nodulation of soybean

The various levels of phosphorus significantly increased the number of nodules $plant^{-1}$ and dry weight of nodule $plant^{-1}$ at 60 DAS. The treatment T_5 i.e. 30:90:30 kg N, P_2O_5 & K_2O ha^{-1} has recorded significantly higher number of nodules (24.5 $plant^{-1}$) and dry weight of nodules (0.35 mg $plant^{-1}$) at 60 DAS. However, it was at par with 30:75:30 N, P_2O_5 and K_2O ha^{-1} (T_4).

5.8 Root length and volume of soybean

Application of different levels of phosphorus significantly increased the root length and volume at 60 DAS. Application of 30:90:30 kg N, P_2O_5 & K_2O ha^{-1} (T_5) recorded significantly higher root length (181.5 cm) and root volume (0.081 cm^3) at 60 DAS. Nevertheless, it was at par with 30:75:30 N, P_2O_5 & K_2O ha^{-1} (T_4).

From the present investigation it can be concluded that,

The higher P adsorption and desorption at higher concentration of P in equilibrium solution showed little effect of fertilization against no fertilization. While, increasing levels of phosphorus has supported to increase the grain and straw yield of soybean along with recommended dose of nitrogen and potassium. Similarly, the higher doses of phosphorus enhanced the uptake of nitrogen, phosphorus and potassium and also the root behaviour significantly. However, increasing levels of phosphorus has proved to enhance residual fertility of available phosphorus against nitrogen and potassium. Therefore, the increasing levels of phosphorus has vital role in yield, uptake, root behaviour of soybean and residual fertility of soil, while it has no significant relationship in respect of adsorption and desorption activities.

CHAPTER VI

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