EFFECT OF WATER SOLUBLE FERTILIZERS THROUGH DRIP FERTIGATION ON YIELD OF SUMMER OKRA, NUTRIENT UPTAKE, NUTRIENT AVAILABILITY AND P FRACTIONS IN INCEPTISOL

by

Mr. Nawghare Vishal Ramesh
(Reg. No. 018/280)

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI – 413 722, DIST. AHMEDNAGAR
MAHARASHTRA, INDIA

in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

IRRIGATION WATER MANAGEMENT

INTERFACULTY DEPARTMENT OF IRRIGATION WATER MANAGEMENT

POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH
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2021

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part

there of has not been submitted

by me or other person to any

other University or Institution

for a Degree or

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This is to certify that the thesis entitled, "**EFFECT OF WATER SOLUBLE FERTILIZERS THROUGH DRIP FERTIGATION ON YIELD OF SUMMER OKRA, NUTRIENT UPTAKE, NUTRIENT AVAILABILITY AND P FRACTIONS IN INCEPTISOL"** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri Dist. Ahmednagar (M.S.) in partial fulfillment of the requirement for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **IRRIGATION WATER MANAGEMENT,** embodies the results of a piece of *bona fide* research work carried out by **Mr. NAWGHARE VISHAL RAMESH,** under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

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LIST OF ABBREVIATIONS AND SYMBOLS

@	:	At the rate of
%	:	Per cent
^{0}E	:	Degree East
^{0}N	:	Degree North
/	:	Per
C.D.	:	Critical difference
cm	:	Centimeter
CPE	:	Cumulative pan evaporation
^{0}C	:	Degree Celsius
DI	:	Drip irrigation
DAS	:	Days after sowing
dSm^{-1}	:	Desi Simen per meter
EC	:	Electrical conductivity
ETr	:	Reference Evapotranspiration
et al.	:	And others
etc.	:	Etcetera
Fig.	:	Figure
g	:	gram (s)
ha	:	hectare
ha-mm	:	Hectare-millimeter
hr	:	Hour (s)
i.e.	:	That is
K	:	Potassium
Kc	:	Crop coefficient
Kg	:	Kilogram (s)
Kg ha^{-1}	:	kilogram per hectare
lph	:	Litre per hour
m	:	meter

mm	:	Millimeter
N	:	Nitrogen
N.S.	:	Non significant
P	:	Phosphorus
PE	:	Pan evaporation
PVC	:	Polyvinyl chloride
Q	:	Quintal (s)
Rs	:	Rupees
S.E.m (±)	:	Standard error means
viz.,	:	Videlicet (Namely)
Kc	:	Crop factor
t	:	Tonnes

ABSTRACT

EFFECT OF WATER SOLUBLE FERTILIZERS THROUGH DRIP FERTIGATION ON YIELD OF SUMMER OKRA, NUTRIENT UPTAKE, NUTRIENT AVAILABILITY AND P FRACTIONS IN INCEPTISOL

By

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Research Guide : Dr. K.D. Kale

Department : Interfaculty Department of Irrigation Water Management

A field experiment entitled, "Effect of water soluble fertilizers through drip fertigation on yield of summer okra, nutrient uptake, nutrient availability and P fractions in Inceptisol" was conducted during the year 2018-2019 at the Research Farm of Interfaculty Department of Irrigation water Management, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar, Maharashtra, India with objectives, to study the effect of water soluble fertilizers on yield of summer okra, periodical uptake of nutrient by okra and nutrient availability, to study the periodical P fractions in soil and its correlation with yield and nutrient uptake and nutrient availability in soil along with economics of okra crop using water soluble fertilizers.

The experiment was carried out in Randomized Block Design with nine treatments replicated three times. The experiment comprised of T_1-DI with 100 % RDF through fertigation, T_2-DI with 80 % RDF through fertigation, T_3-DI with 60 % RDF through fertigation, T_4-DI with 100 % RD of CF (N and K- drip and P-soil), T_5-DI with 100 % RD of CF (soil), T_6 - DI with 100 % RD of fertigation in 7 equal weekly splits, T_7 – Drip irrigation with application of fertilizer as per soil test values, T_8 - DI with no fertigation, T_9–SI with 100% RD of conventional fertilizer (CF).

The result indicated that, the application of water soluble fertilizers significantly enhanced the yield and yield contributing characters (except at 30 DAS) viz., plant height, number of leaves, length of fruits, chlorophyll content, days to 50%

flowering, days to fruit initiation, days to fruit maturity, dry matter content, number of fruits plants^{-1}, weight of fruit plants^{-1} and yield of okra.

Fertigation was found to be more beneficial than conventional method in respect of increasing yield and water saving. The drip irrigation with application of fertilizer as per soil test values produced significantly higher yield (19.55 t ha^{-1}) than all other treatments. However, it was at par with T_1 (18.06 t ha^{-1}), T_6 (17.45 t ha^{-1}), T_2 (16.95 t ha^{-1}) and T_4 (16.85 t ha^{-1}).

The treatment T_7 (DI with application of fertilizer as per soil test values) recorded significantly maximum yield over T_5 (DI with 100% RD of CF) and it indicated that fertigation using water soluble fertilizer dose increased 37.67% in yield over T_5. Total seasonal water requirement in drip was 617.3 mm as compared to 914.9 mm in surface irrigation and resulted into 48.2% water saving.

The dry matter accumulation and total NPK uptake was improved significantly in fertigation treatments over conventional irrigation. Higher dry matter accumulation (24.33 g plant^{-1}) and total uptake (92.85, 45.50 and 74.52 kg NPK ha^{-1}) was recorded in treatment T_7 i.e. drip irrigation with application fertilizer as per soil test values.

Application of water soluble fertilizers through drip irrigation resulted into more nutrient availability than conventional fertilizers. The maximum nutrient availability was observed at 60 DAS. The treatment T_7 recorded maximum availability of N and P (193.5 and 38.5 kg ha^{-1}, respectively) due to application of 125 % RD of N and 100% RD of P whereas as maximum K availability (512.0 kg ha^{-1}) was recorded in T_1 treatment.

In terms of economics, the treatment T_7 (DI with application of fertilizer as per soil test values) was profitable with higher net seasonal income (Rs 2,98,055 ha^{-1}), net extra income over control (Rs. 1,00,077 ha^{-1}), water productivity (Rs. 482.80 ha^{-1} mm).

On the basis of the results obtained, it can be concluded that drip irrigation with application of fertilizer as per soil test values is the best treatment for higher yield, maximum net seasonal income, net extra income over control and productivity of okra (var. Phule Vimukta) cultivated in silty clay soils of western Maharashtra.

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1. INTRODUCTION

Okra commonly called lady finger or Bhendi is one of the most popular and extensively grown vegetable crop all over India. Okra (*Abelmoschus esculentus* L.) or Ladies finger is an annual plant belongs to the family 'Malvaceae'. The place of origin is Ethiopia. There are thirty species under the genus *Abelmoschus* in the old world and four in the new world. Out of them, *Abelmoschus esculentus* is the only species widely cultivated. It is mainly grown in tropical and sub-tropical regions.

India is the largest producer of okra in the world, which contributes to 66.3 per cent of global okra production (Anonymous, 2018). The major growing states in India are Uttar Pradesh, Bihar, West Bengal and Orissa. The crop is grown in India over an area of 509 ('000 ha) with a production of 6094.9 ('000 MT) and average productivity of 12.0 (MT/ha) (Anonymous, 2018). Maharashtra is a okra producing states of India with an area of 13.98 ('000 ha) and production of 139.40 ('000 MT in 2017-2018) (Anonymous, 2018). Dry fruits and skin are useful in paper industry and fibre extraction. Okra is rich source of vitamins, protein, calcium and other minerals. The crop is cultivated for its young tender fruits, used in curry and soups after cooking. It is a good source of vitamins A and B, protein and minerals. The nutritional value of 100 g of edible portion of okra contains 1.9 g protein, 0.2 g fat, 6.4 g carbohydrate, 0.7 g minerals and 1.2 g fibre (Gopalan *et al*., 1989). It is also an excellent source of iodine and is useful for the treatment of goiter. Fruit is useful against genitor-urinary disorders and chronic dysentery. Fruits are also dried or frozen for use during off-season. Dried fruit contain 13-22 per cent edible oil and 20-24 per cent protein and is used for refined edible oil. The root and stems of okra are used for cleaning of cane juice in preparation of Jaggery.

Okra has tremendous export potential as fresh vegetable. India exports okra mainly to West Asia, Western Europe and the United States. It ranks eighth position in area under vegetable crops and occupies second position after onion in export of fresh vegetable of our country. The demand of fresh okra is more in external markets for green, tender and 6-9 cm long fruits. It is also grown during early winter season of mild cool temperatures when price remains very high and farmers earn handsome remuneration from such a crop. It has good potential as foreign exchange earner and accounts for 60 per cent of the export of fresh vegetables excluding potato, onion and garlic. The important vegetable importing countries are middle East, Western Europe and USA (Sharma and Arora, 1993).

Water is one of the most important components for supporting life. With the increasing population of India and its all-round development, the water utilization is also increasing at a fast pace. On an average, India receives an annual precipitation (including snowfall) of about 4000 BCM. However, there exist considerable spatial and temporal variations in the distribution of rainfall and hence in availability of water in time and space across the country. As the world become increasingly dependent on the production of irrigated lands, irrigated agriculture is facing serious challenges that threaten its suitability. It is necessary to make efficient use of water and bring more area under irrigation through available water resources. This can be achieved by introducing advanced methods of irrigation and improved water management practices. Drip irrigation system is found to be effective in 30 to 70 per cent water savings in various vegetable crops along with 10 to 60 per cent increase in crop yield when compared to conventional methods of irrigation.

Conventional methods of irrigation results in losses of nutrients through leaching, surface runoff, absorption on clay fraction and also create adverse condition for plant growth like water logging to some extent. Efficient irrigation techniques are therefore needed for maximizing the efficiency of water and applied nutrients. Drip irrigation is the most efficient method of water utilization for the crop growth. It is an advanced method of irrigation which helps to achieve considerable amount of water saving with high water use efficiency compared to surface irrigation method, where irrigation efficiency is low due to losses in water distribution on the field. Soil is considered as a reservoir for water under surface irrigation and objective of irrigation is mainly to replenish the soil water whereas, under drip method of irrigation, it is possible to apply small quantity of water based on evapotranspiration of the plant (Shikhamany and Shrinivas, 1999).

The application of fertilizer to the field through a drip system is called fertigation. Water soluble fertilizers can be viably and proficiently applied through a drip system. Reduced labour cost, lower equipment and energy cost and higher fertilizer use efficiency are the major benefits of fertigation, compared to the conventional methods of water application. Fertigation offers precise control on fertilizer application and can be adjusted to the rate of plant nutrient uptake. The suitable fertilizers, water soluble fertilizers ready-to-mix (dry liquid fertilizers) such as 19:19:19 are more being used by growers.

Fertilizer is the most basic information which truly influences the development and yield of the harvest, particularly vegetable yields like okra. Significant level of phosphorus in the root zone is fundamental for fast root advancement and great usage of water and different supplements by plant. Phosphorous has an impact on blooming. Phosphorous in mix with N and K improves strip shading, taste, toughness and nutrient content and delays development. Potassium will by and large increment characteristic product size, organic product quality and alters various disarranges. Phosphorus (P) is viewed as one of the most fundamental full-scale components close to nitrogen required for development and advancement of plants (Saber *et al*., 2005). It is coordinated piece of the cell exercises of the living being. Phosphorus plays a significant physiological function in the conservation and transfer of energy in metabolic reactions of every single living cell of the plants (Tisdale and Nelson, 1990). The role of phosphorus has been defined in plant nutrient transport within the plant, break-down of sugar, transfer of genetic characteristics of metabolic pathways (Tandon, 1987). Phosphorus gathered in the leaves will in general arrive at the most extreme at the center of the developing season and diminishes as the plant develops. Its inadequacy brings about hindered development, absence of adequate chlorophyll, contingent upon green and red shade of leaves, irregular/captured root, and it hinders the development of the plant. "Without P there is no cell, no plant and no grain and without adequate P, there is a lot of hunger’’.

The information on different types of P in the soil and the conditions under which these become accessible to plants is an essential in evaluating the availability of P to crops since various types of P have diverse solvency. The accessibility and take-up of P to a great extent relies upon the measures of various parts present in soil (Kothadaraman and Krishnamoorthy, 1979).

The distribution of soil order area in the country under Inceptisols is 95.8 M ha (29.13 %) which is higher than the other soil orders. Most of the soils of central India, being deficient in phosphorus, are unable to supply sufficient quantity of phosphorus for higher grain yield. At present, 5.0 per cent of the Indian soils have adequate available P, 49.3 per cent are under low category, 48.8 per cent under medium and 1.9 per cent under high category (Motsara, 2001). In soils of Maharashtra, available phosphorus is generally low to medium categories (Sonar and Zende, 1984). In Maharashtra state, majority soils are of medium black calcareous soils and in these soils phosphorus fixation is commonly experienced.

In soils, phosphorus can normally be found in different structures. The roots take up phosphorus in $H_2PO_4^-$ and HPO_4^{2-} structures relying on soil pH (Mahidi *et al.,* 2011). However, due to low solubility, mobility and fixation in soils, only a small fraction of phosphorus exists in soil solution (1 ppm or 0.0001 %), which is readily available to plants.

The fundamental essential issues related with phosphorus in soil are: its low versatility, low convergence of accessible P to the plants and obsession of applied phosphorus in the soil. Roughly 15-20 per cent of applied phosphorus is used by the harvests and rest gets fixed in the soil and becomes unavailable to crop plants by forming reaction products of low and varying water solubility through various physico-chemical and biological processes. In the case of acidic soils, free oxides and hydroxides of aluminium and iron play a key role in fixing phosphorus, while in alkaline soils it is fixed by calcium (Toro, 2007). Therefore, phosphorus is often regarded as a limiting nutrient in agriculture soils (Guinazu *et al*. 2010). Thus, phosphorus availability problems are of primary importance in productivity of crops concerning not only its actual deficiency in soil but also its availability to crop plants.

Drip irrigation and fertigation with N fertilizer sources offer what is presumably a definitive in adaptability for N fertilizer management. On the off chance that presumably oversaw, fertigation through drip irrigation lines can decrease generally fertilizer application rates and limit unfavorable natural effect of vegetable production. Fertilizers should be applied in a form that becomes available in synchrony with crop demand for maximum utilization of nutrients from fertilizers (Boyhan *et al*., 2001).

Fertigation is the process where in fertilizer is applied through an efficient irrigation system like drip. In fertigation, nutrient use efficiency could be as high as 90 per cent as compared to 40 to 60 per cent in conventional methods (Solaimalai *et al*., 2005). The application of water soluble fertilizer through micro irrigation system like drip is gaining importance in precision farming. The drip fertigation method is highly efficient method of fertilizer application which is ideally suited for controlling the placement and supply rate of water soluble fertilizers. It can also avoid ground water pollution due to leaching of excessive fertilizers (Pawar *et al*., 2013). The growth, yield and quality of crop are largely influenced by the fertility status of soil apart from genetic potential of the variety. Altering the soil nutrients and fertility status by providing balanced and adequate major nutrients like nitrogen, phosphorus and potassium as per the crop requirement is one of the easiest way to boost up crop productivity (Rajaraman and Pugalendhi, 2013).

A field experiment on growth and yield studies of onion (*Allium cepa* L.) under fertigation was conducted during 2015-16 at Mahatma Phule Krishi Vidyapeeth Rahuri, (M.S.) and reported higher cost of cultivation in micro-irrigation and fertigation treatments than conventional irrigation treatments due to the cost of irrigation systems and higher costs of water soluble fertilizer (WSF). The 100% drip fertigation treatment gave highest net seasonal income, total net income, net extra income over control, B:C ratio, water productivity and it was followed by 100 per cent fertigation through micro sprinkler. The surface irrigation with 100 per cent conventional fertilizer (CF) gave lowest values of all economical parameters than all other treatments (Pol, 2017).

Many researchers have worked on fertigation scheduling, nutrient uptake and availability for different vegetable crops but no research has been done on the okra crop. In view of this, a research trial entitled "Effect of water soluble fertilizers through drip fertigation on yield of summer okra, nutrient uptake, nutrient availability and P fractions in Inceptisol" undertaken with the following objectives.

1. To study the effect of water soluble fertilizers on yield of summer okra.
2. To study the nutrient uptake by summer okra and nutrient availability in soil.
3. To study economics of summer okra as influenced by water soluble fertilizers.
4. To study the periodical P fractions in soil and its correlation with yield, nutrient uptake, nutrient availability in soil.

2. REVIEW OF LITERATURE

For getting more significant yield in okra, a fair utilization of organic manures and inorganic fertilizers is basic. The yield and quality of okra to a great extent relies upon various variables like atmosphere, soil, proper dose and timely application of fertilizers, water system, cultivars, weed management, season of planting, planting thickness and plant assurance and so on. Among them, irrigation and nutrient management is one of the major components which affect the yield and quality of okra.

Therefore, the available literature related to the effect of fertigation schedule for okra through drip irrigation methods on growth, yield and nutrient uptake by okra, nutrient availability and P fractions in soil and economics is reviewed in this chapter.

2.1 Effect of water soluble fertilizers on growth and yield of okra

Hooda *et al.* (1980) reported that the highest green fruit yield was found with N @ 120 kg ha^{-1} and every successive increment in N level resulted in increased vegetative growth and fruit parameters in okra cv. Pusa sawani such as plant height, branches plant^{-1}, fruits plant^{-1}, fruit length and green fruit yield. They also reported significant increased in vegetative growth and yield by application of P @ 30 kg ha^{-1} under Hissar condition.

Kimball (1983) reported that there was enrichment of photosynthesis, growth and yield by increasing the concentration of Co_2 in many crop species.

Dukre (1991) studied okra crop in drip and furrow irrigation methods. He observed that, plant height, mean leaf area, mean root length, number of leaves and dry matter of the plant were significantly higher under drip irrigation method than furrow irrigation method with 100 per cent recommended dose of fertilizer.

Collinson *et al.* (1997) observed the tendency of reduction of stomatal conductance under water stress condition.

Verma and Batra (2001) conducted a field experiment in Haryana, during spring - summer season of 1997 and 1998 on sandy loam soil to study the response of spring okra to irrigation and nitrogen (150 and 200 kg) nitrogen was applied in 3 splits (basal, 30 and 45 days after sowing). They observed that the nitrogen uptake increased with increase in intensity of irrigation and level of nitrogen supply. The highest fruit yield could be ensured with moderate intensity of irrigation.

Gowda *et al.* (2002) conducted a field experiment at Bangalore, (Karnataka, India) to investigate the effects of different fertilizer levels (N:P:K at 125:75:60, 150:100:75 and 175:125:100 kg ha^{-1}) on okra cultivars Arka Anamika, Varsha and Vishal. The highest nutrient uptake and accumulation in leaves and fruits was recorded at the highest level of fertilizer (175:125:100 kg ha^{-1}) in all the varieties.

Sajjan *et al.* (2002) Field studies were conducted in Bagalkot, Karnataka to elucidate the effect of sowing dates (15 June, 15 July (*kharif*), and 15 November and 15 December (*rabi*), spacing (60 x 20, 60 x 30 and 60 x 40 cm) and nitrogen rates (100, 125 and 150 kg ha^{-1}) on the yield attributes and seed yield of okra cv. Arka Anamika during the 1998 *kharif* season and 1998-99 *rabi* season. Sowing on 15 July coupled with 60x30 cm spacing and 150 kg N ha^{-1} recorded the highest yield attributes viz., branches per plant, fruits per plant, 100-seed weight, length and girth of fruits, processed seed recovery and processed yield (1139.7 kg ha^{-1}) in the *kharif* season. However, for the 15 November sowing, with the same spacing (60x30 cm) and nitrogen rate (150 kg N ha^{-1}), the higher seed yield of 745.3 kg ha^{-1} was recorded.

Singandhupe *et al*. (2003) reported that application of nitrogen through the drip irrigation in ten equal splits at 8-days interval saved 20-40 per cent nitrogen as compared to the furrow irrigation when nitrogen was applied in two equal splits (at planting and 1 month thereafter). Similarly, 3.7-12.5 per cent higher fruit yield with 31-37 per cent saving of water was obtained in the drip system. Water use efficiency in drip irrigation, on an average over nitrogen level was 68 and 77 per cent higher over surface irrigation in 1995 and 1996, respectively. At 120 kg N ha^{-1}, maximum tomato fruit yield of 27.4 and 35.2 t ha^{-1} in 2 years was recorded. Total nitrogen uptake in drip irrigation was 8-11 per cent higher than that of furrow irrigation. At the highest level of applied nitrogen (120 kg N ha^{-1}), total average N uptake of 2 years was 64.5 (1995) and 104.7 kg ha^{-1} (1996). The apparent N recovery was 82.5 per cent at 48 kg N ha^{-1} in comparison with 47.9 per cent at 120 kg N ha^{-1} during 1996. Stomatal resistance was higher in furrow irrigation than that of drip system at various plant heights. Lower leaf had less resistance than upper leaf irrespective of irrigation methods.

Omotoso and Shittu (2007) reported that the fertilizer NPK significantly increase growth parameters, (plant height, leaf area, root length, number of leaves) yield and yield components with optimum yield of okra obtained at 150 NPK kg ha^{-1}.

Kushwaha *et al.* (2008) conducted a field experiment to assess the optimum dose of nitrogen and phosphorus fertilizers on hybrid summer okra. Results revealed that each incremental dose of nitrogen upto 150 kg ha^{-1} significantly increased the plant height, number of fruits $plant^{-1}$, pod length, pod girth, pod weight, dry weight of 100 g fresh pod and crop yield. Phosphorus levels upto 80 kg ha^{-1} also significantly increased all the above parameters except pod weight and yield.

Bhanu and Mahavishnan (2008) reported that increased growth and yield with drip irrigation has been reported in several crops and the increase in yield ranged between 7-112 per cent depending on the crops/varieties and method of irrigation compared the water and fertilizer saving through drip fertigation as compared to 75 and 50 per cent RDF through fertigation.

Dougherty *et al*. (2008) conducted sub surface drip irrigation study at Tennessee Valley Research and Extension Centre in 2005. They reported that none of the quality parameters of cotton were significantly affected by different fertilizer treatments except for lint length. Lint length with 100 % fertigated treatments was significantly higher than the fertigated treatments that received surface applied, pre plant nitrogen and potassium.

Firoz (2009) found out the effect of nitrogen (60, 80, 100 and 120 kg ha^{-1}) and phosphorus (80, 100, 120 kg ha^{-1}) on okra [*Abelmoschus esculentus* L.], the highest plant height and number of branches were obtained from 100 kg N and P ha^{-1}, which was statistically at par with 120 kg NP ha^{-1}.

Philip *et al.* (2010) conducted an experiment to study the effect of spacing and NPK fertilizer on the yield and yield components of okra. They reported that spacing of 90 x 30 cm and application of (22.5 kg N, 22.5 kg P_2O_5 and 22.5 kg K_2O) of NPK gave the highest yield of okra in *rabi*.

Reddy and Aruna (2010) conducted a field experiment at Acharya N.G. Ranga Agricultural University, Regional Agricultural Station, Nondyal (Andhra Pradesh). They reported that fertigation with 125 per cent recommended dose of N and K applied as 10 per cent basal and remaining 90 per cent at 30-120 days in nine splits showed higher seed cotton yield of 2.69 t ha^{-1} as compared to recommended manual fertilizer application which gave the seed cotton yield of 2.12 t ha^{-1}.

Zainullah (2010) conducted a field experiment at Precision Farming Development Centre (PFDC) GKVK, UAS, Bangalore to study the effect of spacing and fertigation on growth, yield and quality of okra [*Abelmoschus esculentus* (L.) Moench] Var. Arka Anamika. They reported that the cultivation of okra with spacing of (60 cm x 45 cm) and fertigated with water soluble fertilizers (WSF) at the rate of 156:93:75 kg NPK ha^{-1} given maximum yield 14.60 t ha^{-1} with good fruit quality compare to all other treatments.

Mahedran *et al*. (2011) conducted a field experiment at AICRP- Water Management block, Agricultural College and Research Institute, Madurai during *Kharif* 2009, to study the effect of drip fertigation on growth, yield, quality and economics of hybrid Bhendi (M-10). They reported that the drip fertigation of 100 per cent RDF as WSF registered significantly higher pod yield which amounted to 65 per cent yield increase over surface irrigation with soil application of recommended dose of fertilizers.

Venkadeshwaran *et al.* (2014) studied the effect of conventional fertilizers and water soluble fertilizers at varying frequency interval of application on growth and physiological attributes of okra (*Abelmoschus esculentus* L.). No significant differences could be observed for days to flowering, number of primary branches $plant^{-1}$ at flowering as well as final harvest and node of first flower appearance.

Varughese *et al.* (2014) studied the effect of fertigation levels and drip system layout on performance of okra under plastic mulch at Kelappaji College of Agricultural Engineering and Technology, Tavanur, Malappuram, Kerala during *summer* season. They reported that fertigation with 120 per cent of recommended dose (N:P:K @50:8:25 kg ha^{-1}) gave maximum yield of 421.7 g $plant^{-1}$, which was at par with that of 100 per cent level of recommended dose (371.8 g $plant^{-1}$).

Mohsen *et al. (*2015) reported that application of different levels of nitrogen plus phosphorus fertilizer combined with or without compost. Significantly ($p<0.5$) influenced the growth yield and other attributes of okra plants. Application of

100 kg N fed^{-1} + 75 kg P fed^{-1} with or without compost to okra plants gave the highest values of plant growth, yield and quality in the two studied season.

Bhende *et al.* (2015) evaluated the effect of phosphorus and potassium was found to be effective on different attributes like fruit length, fruit weight, number of seed per dry fruit, seed yield per plant, weight of seed per dry fruit and seed yield per plot were found significantly increased with application of 75 kg P ha^{-1} and 75 kg K ha^{-1} in okra cv. Arka Anamika.

Hari and Ramesh (2017) conducted an experiment to study the yield response of okra [*Abelmoschus esculentus* (L.) Moench] for different row spacing's and fertilizer application methods under drip irrigation during February-May 2015. Two row spacing's 40 × 40 cm and 50 × 40 cm were chosen. Fertilizer application in two methods viz. through fertigation tank and by manual application was considered. The analysis of data indicated that the yield response of okra was considered to be the better combination in 50 × 40 cm spacing with fertilizer application through fertigation tank when compared to other spacing and manual application of fertilizer. The pod parameters like pod perimeter, pod length, and pod width are also well influenced by the row spacing of 50 × 40 cm with the method of fertigation, as these values are observed to be best. The vegetative growth characteristics like plant height and number of branches are also reasonably good in 50 × 40 cm spacing and fertigation as compared to all other treatment.

Nair *et al.* (2017) studied that application of recommended dose of fertilizer (180:120:120 kg NPK ha^{-1}) through fertigation using water soluble fertilizer on the performance of okra [*Abelmoschus esculentus* L. (Moench)]. The weekly interval resulted in higher values for plant height (153.6 cm), pods per plant (15.79 cm), pod length (16.33 cm), pod girth (6.48 cm) and pod weight (21.28 g) which remained on par with same amount of fertilizer applied bi-weekly.

Singh *et al*. (2018) carried out field experiment to study the response of okra [*Abelmoschus esculentus* L. (Moench)] growth, yield attributes and economics to irrigation levels and mulching. The field was divided into three blocks, in which each block was assigned to four drip irrigation levels (irrigation treatments consisted 15 per cent Available soil moisture depletion (ASMD) (I_1), 30 per cent ASMD (I_2), 45 per cent ASMD (I_3) and 60 per cent ASMD (I_4). Soil cover treatments (black plastic mulch, wheat straw and no mulch) were randomly distributed according to 4 x 3 factorial arrangements with randomized complete block design. Black plastic mulch treatments produced significantly higher yield than other mulch treatments. Average fruit length and fruit weight of okra were also affected by different mulch treatments. Generally fruit length and weights of okra were 11.2 and 13.9 per cent higher in black plastic mulch than bare soil, respectively. Using plastic mulch as soil cover significantly increased marketable yield of okra and their components compared with bare soil. Total yield of okra and fruit number using plastic mulch was about 49.3 and 52.4 per cent more than without mulching respectively. The treatment, M_3I_2 recorded considerably highest values of income from produce (Rs. 344,040) with net income of (Rs. 199, 753) per hectare, respectively with a B:C ratio of 1.38. It is recommended that farmers of similar agro-ecology should schedule irrigation at 30 per cent available soil moisture deficit in combination of using black plastic mulch to produce higher okra yield.

Krittika and Misal (2018) conducted experiments in the field at the Soil and Water Engineering Department research farm, PAU, Ludhiana during March-July 2015, which aimed at knowing the optimum irrigation level and doses of fertilizer. The layout chosen for this experiment was randomized block design including three replications. The fertigation treatments applied were 60 % of recommended dose of fertilizer (F_1), 80 % of recommended dose of fertilizer (F_2) and 100 % of recommended dose of fertilizer (F_3) in main plots. Three irrigation levels based on crop evapotranspiration were 0.6 Etc (I_1), 0.8 Etc (I_2) and 1.0 Etc (I_3). Okra yield was maximum in I_2 F_2 treatment (211.6 q ha^{-1}) with an increased yield of 27.01 per cent over traditional method. The results revealed that there was significant effect of irrigation and fertilizer treatment as well as its combination on yield but the effect was not significant on plant height and plant population.

Kale *et al.* (2018) conducted field experiment at MPKV, Rahuri to study the yield and economics of hybrid tomato as influenced by different level of fertigation and reported that the plant height, number of branches plant^{-1}, leaf area, number of fruits plant^{-1}, weight of fruits plant^{-1} and yield were significantly maximum in 100 per cent recommended dose of fertilizer.

2.2 Effect of fertigation on nutrient availability and nutrient uptake by okra

Bharambe *et al.* (1997) reported that the higher nutrient use efficiency under drip fertigation with water soluble fertilizer over conventional practice could be attributed to the regular application of nutrients (14 splits) combined with irrigation water in the active root zone of the cotton crop resulted into enhanced production and minimum loss of nutrients from root zone.

Balsubramanian *et al.* (2000) conducted a field trial on fertigation in cotton hybrid, RCH-2 at Nagarjuna Agricultural Research and Development Institute, Warangal, Andhra Pradesh. They reported that fertigation (nitrogen and potassium) improved the fertilizer use efficiency by saving 25 % of fertilizers.

Patel and Rajput (2003) observed that drip fertigation in bhendi has resulted in higher Nitrogen use efficiency (70 kg kg^{-1} N) over broadcasting of nitrogen (48.7 kg kg^{-1} N).

Punamhoro *et al.* (2003) studied the performance of bhendi under different irrigation methods *viz.*, drip irrigation with bucket kit and drum kit, micro sprinkler, over head sprinkler irrigation, flood irrigation, check basin irrigation and furrow irrigation. The results of the study revealed that highest WUE of 2.52 q ha^{-1}cm was recorded in drip irrigation with bucket kit, while the lowest WUE of 1.06 q ha^{-1} cm was noticed with flood irrigation.

Singandhupe *et al*. (2003) reported that nitrogen uptake was significantly influenced by the irrigation schedule during first year. Due to frequent application of irrigation and fertilizer in drip irrigation, nitrogen was effectively utilized, as there was direct contact with the root system with negligible N loss through leaching, as applied irrigation water did not move beyond 30 cm soil depth. But in furrow irrigation, since nitrogen was applied only in two equal splits, effective utilization was reduced particularly during the drying cycle as soil moisture was depleted with time. Hence, total N uptake of plants in furrow irrigation was reduced by 10 per cent during 1995 as compared to the drip method.

Kumar *et al.* (2006) conducted field experiment to find out the effect of application of N and K levels on uptake of nutrients by the onion with four levels of nitrogen and potassium (0, 50, 100 and 150 kg ha^{-1}) and 100 kg P_2O_5. They revealed that, the maximum N content in bulb was from 1.12 to 1.4 per cent, P content of bulb was from 0.2 to 0.27 per cent and K content of bulb was from 1.25 to 2.34 per cent.

Thind *et al.* (2008) conducted field experiment at regional research station, Bathinda, Punjab Agriculture University. They reported that high seed cotton yield under fertigation was due to more N uptake, fertilizer N utilization efficiency as compare to soil application.

Jadhav *et al.* (2008) conducted field experiment, to study the nutrient uptake and yield of okra as influenced by integrated plant nutrient supply. They reported that the recommended dose of NPK (100:50:50 kg ha^{-1}) along with 10 Mg FYM ha^{-1} and Azospirilum recorded highest nutrient uptake of 41.29 kg N, 3.99 kg P, and 42.11 kg ha^{-1}. The combine use of organic manures, inorganic fertilizers and biofertilizer (NPK+10 Mg FYM ha^{-1} +Azospirilium) registered the highest fruit yield (92.71 q ha^{-1}).

Patil *et al*. (2009) observed that uptake of N, P and K by cotton was found maximum with irrigation applied at 1.0 Etc, along with 125 per cent recommended dose of fertilizers (125:62.5:62.5 kg NPK ha^{-1}).

Imamsaheb *et al.* (2011) showed that higher uptake of nitrogen, phosphorus and potassium by tomato plant was recorded with 100 per cent recommended NPK as compared with 75 and 50 per cent recommended NPK.

Al-Mohammadi and Al Zubi (2011) carried out an experiment in greenhouse during winter season at Experimental Station, Al-Balqa University, Jordan to evaluate irrigation and fertigation levels on yield and quality of tomato crop. The results indicated that content of nitrogen, phosphorus and potassium in tomato leaf significantly increased with increase in levels of fertilizers and quantity of water.

Jamrey (2013) studied the growth and yield using different irrigation and fertigation schedules by drip irrigation and to suggest the most efficient fertigation schedule that would attain the highest growth and yield of okra crop. They reported that the fertilizer use efficiency was higher under T_7 (75 % RDF through fertigation in equal splits at 5 days interval) 353.48 kg ha cm as against a minimum of flood and drip treatments. The fertilizer use efficiency was lower at lower level of fertilizer application (50 %) as compared to higher level of fertilizer (100 %). It was higher under T_{10} (50 %

RDF through fertigation in equal splits at 5 days interval) i.e. 264.61 kg yield kg^{-1} nutrient as against a minimum of flood and drip treatments.

Salvi *et al.* (2014) carried out field experiment during *kharif* season of the year 2007 with Okra Cv. Pharbhani Kranti on lateritic soil of Kokan region at central experiment station. They reported that the yield, dry matter of plant and N, P, K, Ca, Mg, Zn, Bo in plant increased with integrated use of manure, fertilizer and biofertilizer.

Wagh *et al.* (2014) studied the effect of INM on nutrient uptake, yield and quality of okra. They found that highest nutrient uptake by okra, yield of okra (no. of fruits $plant^{-1}$, weight of fruit yield $plant^{-1}$) and quality attributing characters i.e. high protein contents and low crude fiber content of okra fruits recorded in treatments receiving 100 % RDF over other treatments which was statistically at par with treatment 75 % RDF + 12.5 % RDN through vermicompost + 12.5 % RDN through neem cake followed by treatments. 75 % RDF + 25 % RDN through vermicompost and 75 % RDF + 25 % RDN through neem cake.

Pushaphavali *et al.* (2014) reported that the application of 100 % K recommended dose through K ash recorded the highest okra yield which was 31 per cent increased yield over 100 % K recommended dose through muraite of potash, K ash application recorded numerically higher value than the other treatments. It was concluded that K ash could be used as alternate organic K source for chemical K fertilizer in the okra production.

Madhusoodana (2016) found that cultivation of *kharif* cotton on medium deep clayey soils can be extended up to March (providing drip fertigation with 150 % recommended dose of WSF as per schedule (up to 161 DAS) to obtain higher seed cotton yield, efficient water and nutrient use and economical returns in western Maharashtra.

Jana *et al.* (2017) conducted an experiment to evaluate the periodical nutrient availability in Bt. cotton under drip fertigation by using different P sources. The results indicated that 100 % RD of fertigation (24:24:0) registered significantly maximum NPK availability at 90 DAP as compared to SI with CF and gradually it decreases at harvesting stage. The nutrient availability decreased at harvesting stage may be due to uptake of more nutrients at harvest as compared to 90 DAP.

Arunnaik *et al.* (2018) found that the application of 125% RDF recorded significantly higher nitrogen, phosphorus and potassium content in okra fruits (2.69, 0.34 and 2.23 %, respectively), while lower nitrogen, phosphorus and potassium content was observed in STCR approach (2.35, 0.26 and 2.04 % respectively). Significantly higher content of nitrogen, phosphorus and potassium in fruit (2.95, 0.37, 2.04 %, respectively) was observed with spacing 60 x 30 cm whereas lower nitrogen, phosphorus and potassium content (2.21, 0.24 and 1.86 %, respectively) in fruit was observed in spacing 60 cm x line sowing.

Singh *et al.* (2018) conducted field experiment during *kharif* season of 2010, to study the effect of INM on growth, yield and quality of okra var. Prabhani Kranti. They reported that maximum green pod yield (78.20 q ha^{-1}), N-uptake 74.50 kg ha^{-1} and P- uptake 6.80 kg ha^{-1}. The highest level of N and P_2O_5 (120 kg ha^{-1}) also augmented the above parameters up to the same extent.

2.3 Economics of okra under fertigation

Mahale (2000) found that drip tape irrigation system in *kharif* soybean was better as it resulted in maximum benefit: cost ratio of 2.32:1 which was 18.97 per cent more over that of drip system with 45 cm emitter spacing.

More (2000) studied the effect of micro irrigation system and N fertigation level on yield and quality of onion bulbs and reported that maximum benefit: cost ratio (9.39) was recorded in the treatment with drip tape with 125 % recommended dose of N.

Ahire *et al.* (2002) conducted a field experiment on entisols to determine the economics of different planting systems and irrigation methods of potato during the *rabi* season of the year 1997 in Maharashtra, India. They observed that in drip irrigation the highest gross returns, the lowest cost of production, the highest net income and the highest benefit: cost (B:C) ratio were obtained than the surface irrigation.

Pawar *et al.* (2002) studied effects of sprinkler, drip and surface irrigation method and NPK rates on the yield of potato. They concluded that sprinkler method gave the highest net returns (Rs. 42,850 ha^{-1}) and benefit: cost ratio (2.93).

Lawal and Rahman (2007) conducted an experimental trail in north Nigeria. They reported that intercrops of okra and pepper gave better yield and economic returns with application of 400 kg ha^{-1} of inorganic fertilizers, 5 t ha^{-1} of manure and 10-day irrigation intervals.

Singh *et al.* (2010) conducted an experiment at Precision Farming Development Centre, IARI, New Delhi to study the response of micro-irrigation and fertigation on high value crops under control conditions and found that N application through fertigation registered maximum net income under polyhouse cultivation of tomato.

Ranjan *et al.* (2012) they reported that the highest nutrient uptake in respect of N, P and K yield as well as net-return in okra was recorded from the treatment supplied with 25 per cent of recommended dose of nutrient through FYM. It was closely followed by the combination of inorganic in the same proportion. These two treatments and the treatments pertaining to the application of recommended dose of fertilizers in respect of NPK uptake, yield and also economics exhibited beneficial effect in terms of net return in comparison with full dose of inorganic nutrient.

Hadole (2013) conducted a field experiment on nutrient management in cotton under drip irrigation at Dr. PDKV, Akola (MH) during 2000 to 2003 with three fertilizer levels (50, 75 and 100 % RDF) and two times of splitting (three and five). They reported that the highest gross monetary returns were obtained from 100 % RDF in 5 splits followed by same dose in 3 splits. The B:C ratio was increased when fertilizer applied through fertigation than conventional method even with the lower dose.

Pawar *et al.* (2013) noted that the high installation cost is the major limitation of drip for its adoption by farmers. The costs vary with crop due to changes in emitters and laterals spacing. Drip costs are lowest for widely spaced orchard crops but for close growing vegetables it may be little higher.

Narayanmoorthy and Devika (2017) reported that the drip method of irrigation (DMI) can reduce about 47 per cent of water resources and electrical energy, and augment about 49 per cent of productivity of okra over the same crop cultivated under conventional flood method of irrigation (FMI).

2.4 Soil phosphorus

Phosphorus occurs in soil in a few structures which can be grouped into three categories viz. Inorganic P, organic P and soil solution P. The information on types of phosphorus is valuable in various parts of soil science, soil beginning and soil ripeness. The knowledge of various forms of phosphorus present in soil and the conditions under which these becomes available to plants is prerequisite for assessing the availability of phosphorus to plants. Since different forms of soil P have different solubility, the availability and uptake of phosphorus largely depends upon the amount of different fractions present in soil. The relative distribution of various forms of phosphorus varies with climate, parent material, vegetation and soil properties. Marked variation in different forms of inorganic P is function of genetic differences among the soils (Chang and Jackson, 1958).

Chang and Chu (1961) reported that over comparatively short periods and in relatively dry soil, added soluble-P is mainly fixed as Al-P followed by Fe-P and then by Ca-P regardless of the soil pH. When the time of contact prolonged, the amount Fe-P increased and the amounts of AI-P and Ca-P decreased accordingly. Further, the rate of change increased with the moisture content of soil.

Pagel *et al.* (1967) stated that in the soils of humid tropics, total P content mainly depend on the degree of weathering and genesis of soil. Apart from organic P compounds Al-P and Fe-P prevailed in ferralactic soils and Ca-P dominated in Vertisols. The effect of pH on inorganic forms of P was marked and its increase resulted in an increase in Ca-P and a decrease in Fe-P and vice-versa.

Srivastava and Srivastava (1993) studied various forms of P viz., adsorbed P, Al-P, Fe-P, Ca-P and Red-P in relation to varying soil pH, availability of P under air dried and waterlogged condition and response to P application in saline-sodic soil under rice-wheat crop sequence and concluded that Ca-P was observed as the most predominant P fraction followed by Red-P, Fe-P, Al-P, and adsorbed P in soil pH ranges from 7.2 to 10.3.

Kulkarni (1994) studied the forms and Q/I relationship of phosphorus in six widely spread soil series of central campus farm Rahuri to understand the behaviour of P in surface and subsurface layers of these soils. The total P and total mineral P contents are high which might be attributed to the high contents of Ca-P and reductant soluble P in these soils. The Ca-P contributed to the bulk of the total-P (46 %) followed by Red-P (6.7 %) in all the soil series under study with equilibrium among the different forms as evident from the significant relationship among various forms of P.

Tamboli (1996) studied inorganic phosphorus fraction in Vertisol and Alfisol and their utilization by legumes and concluded that in vertisols Ca-P most dominant inorganic P fraction followed by Red-P irrespective of P sources applied. Next in order was Fe-P. In Alfisol, Fe-P was the dominant fraction followed by Red-P and Ca-P fraction irrespective of P sources applied. The Al-P and saloid-P were the least dominant fractions even when $AlPO_4$ was applied in both Vertisol and Alfisol.

Singh *et al.* (2003) studied phosphorus fractions and their relationship to weathering indices in Vertisols. The Ca-P, available, organic and total P was higher in younger Vertisols of Taswaria and Taswaria sodic series, derived from calcicgneiss complex, whereas the Al-P, Fe-P and Occluded P fractions maintained their higher concentrations in the older vertisols of Patan and Aklera series, originating from basalt. Vertisols of Chambal and Kota series, developed on basaltic alluvium, were intermediate between these two types. Variations in parent materials failed to account for the close resemblance of Vertisols of Bhatewar series developed from gneiss complex to that of Patan and Aklera series derived from basalt with respect to the fractions of phosphorus.

Laxminarayana (2005) studied distribution of Inorganic P fractions and critical limits of available P in rice soils of Mizoram and reported that the sequential occurrence of various inorganic P fractions followed the order Red-P > Fe-P > Al-P > Ca-P > S-P. Total P in the soils ranged from 132.3 to 365.8 mg kg^{-1} with mean of 245.5 mg kg^{-1}. Distributions of total P in these soils are Red-P (34.0 %), Fe-P (15.8 %), Ca-P (12 %), Al-P (19.6 %) and Sal-P (2.46 %). The inorganic P constituted 75 per cent of total P, it ranged from 119.7 to 233.0 mg kg^{-1} (mean of 181.2 mg kg^{-1}), where as the organic P varied from 11.0 to 132.8 mg kg^{-1} (mean of 61.3 mg kg^{-1}).

Trivedi *et al.,* (2010) studied forms of phosphorus and their distribution in eighteen profiles of Alfisols and Inceptisols of Gird region of Madhya Pradesh in relation to soil properties. In both orders amount of Sal-P, Fe-P, Al-P, Red-P and total-P decreased with increasing depth, whereas Ca-P was found to be lower in the surface layers and increased with depth. The Ca-P was observed to be most predominant P fraction followed by Red- P, Al-P and Fe-P in soil pH range of 6.8 to 10.1.

2.4.1 Inorganic soil phosphorus

It includes both definite P compounds and surface P held on mineral particles. The inorganic P occurs in numerous combinations with Fe, Al, Ca and other elements. These compounds are usually only slightly soluble in water. Phosphorus also reacts with clays to form insoluble clay- phosphate complexes. Generally, the content of inorganic-P in soil is always higher than that of organic-P.

Anjaneyulu and Omanwar (1979) found that applied P retained in a decreasing order as Ca-P, Al-P and Fe-P and the relative intensity of change in P forms was more in Al-P (89 %), less in Ca-P (19 %) and least in Fe-P (14 %) under long term experiment with wheat-maize rotation in clay loam soil after eight years.

Prasad *et al.* (1986) studied that the forms of phosphorus and response of wheat in vertisols of Bihar. They reported that all the P forms were related to each other.

Pattanayak and Misra (1989) studied total P content of twelve acid soils belonging to Alfisols, Entisols and Inceptisols of Orissa and reported that upon submergence, the organic P transforms into inorganic P fractions in soil due to hydrolysis of organic matter.

Rokima and Prasad (1991) studied the transformation of applied P into inorganic P fractions in relation to its availability and uptake in calcareous soils. They observed that all the P fractions were found to be correlated with yields (r=0.77* to 0.99*) in soybean.

Bhardwaj *et al.* (1994) studied long term effects on continuous rotational cropping and fertilization on crop yields and soil properties. III. Changes in the fractions of N, P and K of the soil. They observed that total-P had high degree significant and positive relationship with all the inorganic P fractions.

Kulkarni (1994) studied 6 soil series Nimone, Otur from Vertisol soil order, Sawargaon, Dholwad from Inceptisol soil order and Khanapur, Paregaon from Entisol soil order of MPKV campus Rahuri and concluded that Total-P contents were also quite high which be attributed to the high contents of Ca-P and Red-P in these soil. The Ca-P contributed to the bulk of the Total-P (46 %) followed by Red-P (67 %).

More and Agal (1994) studied the effect of P sources on phosphorus transformation and its availability in vertisol. They reported that the NPK availability is positive and significant with all P fractions except Al-P, Ca-P and Total-P.

Gajbhiye (2001) studied distribution of phosphorus fractions in Vertisols and associated soils of Nagpur district. The soils were clayey in texture, neutral to alkaline in reaction (pH 7.4 to 8.3) and slightly to highly calcareous (1.31 to 12.8 %). The major part of total P (105 to 938 ppm) was contributed by inorganic P (58.5 to 94 %) out of which Ca-P contributed about 30.8 to 82 per cent because Ca-P was positively correlated with pH and $CaCO_3$ of soil. Whereas, Al-P, Fe-P, Saloid-P and Red-P was negatively correlated with pH and $CaCO_3$.

Majumdar *et al.* (2004) concluded that the inorganic P fractions in the soil under various farming system showed significant variation in all the slope portions. Agriculture land use (FSW4) recorded significantly highest value of all the forms of inorganic P on each top, middle and bottom portions of the watersheds.

Sarawagi *et al.* (2012) studied the effect of phosphorus application along with PSB, Rhizobium and VAM on P fractionation and productivity of soybean (*Glycine max*). They reported that the highest values for P fractions were recorded at 60 and 90 DAS.

2.4.2 Soil solution phosphorus

Phosphorus is consumed by plants as essential and optional orthophosphate ions ($H_2PO_4^-$) which are available in soil arrangement. Assimilation as essential orthophosphate is bigger than the last structure. Small amounts of dissolvable natural structure may likewise be retained; however they are commonly viewed as minor significance. The concentration of these ions in the soil arrangement and the support of this fixation are of most noteworthy significance to plant development, the two of which rely to a great extent upon the moderately pace of natural issue deterioration and the capacity of the soil inorganic fraction to respond with or fix solvent orthophosphate in an insoluble or marginally dissolvable structure.

2.4.3 Organic soil phosphorus

The nature and responses of organic soil P are not all that surely knew as those of inorganic soil P. The natural mixes of P are more unpredictable than inorganic P mixes deal with natural P is, in this way, restricted and none of the techniques being used is seen as palatable. Natural P enters in the soil viz., as plant as well as creature deposits. Natural P part in humus and other natural materials might possibly be related with it. In soil, it happens in three chief structures for example phospholipids, nucleic acid and inositol phosphates.

Rane and Patel (1989) fractionated the black calcareous soil (Vertisols) and found that dominant P fraction was organic P under groundnut- wheat sequence.

Patgiri and Dutta (1993) studied on forms and distribution of phosphorus in some tea growing acid soils and reported that organic P contents ranged from 325 to 531 ppm. Organic P had significant positive correlation with organic carbon ($r = 0.54^{*}$) and total P ($r = 0.82^{**}$) whereas it had significant negative correlation ($r = -0.59^{*}$) with soil pH.

Singh *et al.,* (2003) studied phosphorus fractions and their relationship to weathering indices in Vertisols and concluded that organically bound phosphorus constituted 30-52 per cent of total P in Vertisols and mean content of this form of phosphorus was 160 and 152.6 mg kg^{-1} in Taswaria and Taswaria sodic series, which was higher as compared to other series included in the study. Mean content of 71.7, 87.8 and 110.5 mg kg^{-1} in Patan, Bhatewar and Aklera series, respectively was lower than the other forms. However, mean of organic P was 120 to 130 mg kg^{-1} in Kota and Chambal series representing the intermediate values between the two types. Organic P accumulated higher at surface and run parallel to the organic carbon content.

2.5 Different forms of phosphorus

i. Saloid bound phosphorus

Saloid bound P also referred as adsorbed P highly available to plants. Usually there exists a sort of equilibrium between the adsorbed P and that present in soil solution (Singh and Pathak, 1972). In the soils of North-West Rajasthan Saloid P ranged from 15.9 to 23.4 ppm and available phosphorus from 7.7 to 11.8 ppm (Talathi *et al.,* 1975). This may be considered advantageous for releasing more available phosphorus from this fraction.

Bhan and Shankar (1973) observed that saloid-P exhibited significant positive correlation with Al-P ($r = 0.672^{*}$) and Ca-P ($r = 0.554^{*}$).

Kothandaraman and Krishnamoorthy (1979) reported that low values of Saloid-P in the soils of Tamil Nadu from 6 to 70 ppm.

Agrawal *et al.* (1987) reported the saloid-P ranged from 1.5 to 12.0 mg kg^{-1}, but due to application of phosphatic fertilizers it increased significantly.

Pattanayak and Misra (1989) reported that in acid soils of Orissa the contribution of saloid-P to inorganic pool was negligible ranging from 0 to 5 ppm (0 to 3.5 per cent of total inorganic P) and Olsen's P of the soils showed significant positive correlation (r =0.82**) with saloid P.

Viswanatha and Doddamani (1991), indicated that saloid-P content of the soils decreased with depth in all the profiles and the content varied from 1.0 mg kg^{-1} (80-100 cm) in Hirekumbi series to 3.7 mg kg^{-1} (0-20cm) in Hebsur series. The mean value of saloid-P of surface samples ranged from 2.6 mg kg^{-1} (Kiresur series) to 3.4 mg kg^{-1} (Hebsur series). The higher value of saloid-P at the surface layers may be due to mixing of P from fertilizer and manures in the surface soil.

ii. Aluminium and Iron phosphates

Ramdeo and Ruhal (1970) found that the solubility of Ca, Al, and Fe compounds are controlled by soil pH.

Mengal (1985) studied that Al-P and Fe-P are major parts of absorbed-P in mineral soils with pH below 7 these fractions are dominant.

Tripathi and Minhas (1991) reported that in Typic Hapludalf, the major portion of added P was transformed in to Al-P (23.8%) followed by Fe-P (21.9%). The higher value of Al-P than those of Fe-P were found in soils treated with rock phosphate, whereas reverse trend was observed in the case of superphosphate treatments.

Dongale (1993) studied depth distribution of different forms of phosphorus in lateritic soils of coastal region and reported that deeper layers in the Wakawali, Gavhane and Kudal profiles are richer in Fe-P as compared to surface layers whereas a reverse trend, in general is noticed in Shirgaon, Math and Niruade profiles. Content of Al-P varies from traces to 36 ppm in different profiles.

Sihag *et al.* (2005) studied the effect of integrated use of inorganic fertilizers and organic materials on the distribution of different forms of N and P in soil and reported that the amount of Al-P and Fe-P ranged from 39.8 to 49.5 mg kg^{-1} and 60.5

to 68.4 mg kg^{-1} respectively. The Al-P and Fe-P accounted for 8.4 and 12.1 per cent of total prospectively.

Talashilkar *et al.* (2006) studied influence of soil reaction on soil acidity parameters and fractions of organic matter, nitrogen, phosphorus and potassium in lateritic soils of Konkan region. Phosphorus fractions Fe-P and Al-P exhibited reduction in slightly acidic soils than in very strongly acidic soils, whereas all other P fractions were increased with rise in pH.

iii. Reductant soluble phosphate (Red-P)

Bapat *et al.* (1965) noted that the Red-P fraction constitutes fairly large proportion of inorganic P in Vidarbha soils of Maharashtra.

Vijay *et al.* (1972) studied that the lower percentage (0.86 % of total inorganic-P) of Red-P was observed in medium black soils of Chambal command area.

Shrivastav and Pathak (1972) repoted that the low occluded Fe-P content could be attributed to slow process related to soil genesis.

Dongale (1993) studied depth distribution of different forms of phosphorus in lateritic soils of coastal region and reported that reductant soluble P plus occluded P (less active) accounts for 16.1 to 43.2 per cent of total P and the former dominates latter. In six out of eight profiles Red-P is maximum in surface horizon which decreases with increase in the depth.

iv. Calcium bound phosphorus

The proportion of Ca-P increased with soil pH and calcium concentration in the soil. Thus in calcareous soils, the formation of Ca-P tended to prevail. Solubility and availability differed considerably and followed the sequence: $CaHPO_4H_20$ (Brucite) > $CaHPO_4$ (Monetile) > $Ca_8H_2(PO_4)_6.5H_2O$ (Octa-calcium Phosphate) P-$Ca_3(PO_4)_2$ (P-tricalcium phosphate) > $Ca_{10}(PO_4)_6(OH)_2$ (Hydroxy apatite) > $Ca_{10}(PO_4)_6F_2$ (Fluroapatite) (Mengel, 1985).

Transition of Ca-P from one form to another could be described by following equations:

$$Ca\,(H_2PO_4)_2 + Ca^{2+} = 2\,CaHPO_4 + 2H^+$$

$$6\,CaHPO_4 + 2\,Ca^{2+} = Ca_8H_2\,(PO_4)_6 + 4H^+$$

$$Ca_8H_2\,(PO_4)_6 + 2Ca^{2+} + 2H_2O = Ca_{10}\,(PO_4)_6(OH)_2 + 4H^+$$

The reaction sequence showed that under high pH conditions and abundant Ca^{+2} the formation of apatite is favoured. A reverse reaction is true if apatite is exposed to low Ca^{2+} and high H^{+} concentration.

Kolambe (1992) reported that Ca-P is the most dominant form of P in 21 swell-shrink soils of Maharashtra. The range was 37.7 to 465 ppm with an average of 67.3% of total mineral P. The Ca-P ranged from 19 to 48 mg kg in eight representative profiles of Alfisols, Inceptisols and Entisols from Uttar Pradesh (Singh and Omanwar, 1987). Studies carried out by Kulkarni (1994) for six soil series of Maharashtra revealed that the total mineral P content were quite high which might be attributed to the high content of Ca-P and reductant soluble P in these soils. The Ca-P contributed to the bulk of the total –P (46 %).

Singh *et al.,* (2003) reported that Vertisols of Taswaria and Taswaria sodic series derived from calcicgeneiss complex were higher in Ca-P with mean of 84.1 and 88.9 mg kg^{-1} respectively. The mean Ca-P was 41.0, 51.5 and 53.3 mg kg^{-1} in pedons of Patan, Aklera and Bhatewar series, respectively. Pedons of Chambal and Kota series had 58.7 and 52.6 mg kg^{-1} of Ca-P.

Neha Ranjan (2018) studied the effect of different P sources through fertigation on yield, nutrient uptake by tomato and nutrient availability and P fraction in inceptisols and reported that the highest value for P fraction were observed in treatment of 80 % RDF through fertigation at 60 DAT as Ca-P (420.37 ppm) followed by red-P (92.67 ppm), Al-P (37.45 ppm), Fe-P (35.33 ppm), Sal-P (20.94 ppm), occl-P (20.63 ppm) and total-P (853.93 ppm).

v. Occluded phosphorus

According to Walkar and Syres (1976) Ca-P decreases during pedogenesis and occluded-P increases. Thus weathered acid soils are rich in occluded-P while their Ca-P content is almost nil.

Kolambe (1992) from the study of 21 vetric soils of Maharashtra found that occluded-P varied from 3.3 to 18.5 ppm for Sawargaon and Hingona series, respectively. It contributed 0.63 to 6.2% of total mineral P with an average of 2.3%.

Singh *et al.,* (2003) studied the P fractions and their relationship to weathering indices in Vertisols and concluded that occluded phosphorus was found to be higher in Vertisols of Patan, Bhatewar and Aklera series with mean value of 16.6, 14.20, 13.10 mg kg^{-1}, respectively. Vertisols of Taswaria and Taswaria sodic series were lowest in these forms of phosphorus, with a mean content of 6.6 and 5.4 mg kg^{-1}. Vertisols Chambal and Kota series had 11.45 and 9.20 mg kg^{-1} mean content of occluded phosphorus.

vi. Total phosphorus

Bapat *et al.* (1965) noted that Vidarbha soils of Maharashtra contain high total P (266 to 847 ppm).

Viswanatha and Doddamani (1991) reported that total-P generally decreased with depth in all the profiles. The decrease in total-P might be attributed to decrease in organic phosphorus content with increase in depth. The total-P content in profile samples varied from 156.8 (Kieresur) to 372.7 mg kg^{-1} (Hirekunbi) and mean values from 318.3 (Nalvadi series) to 374.5 mg kg^{-1} (Hirekunbi series) in surface samples. The high content of total-P in surface layers might be attributed to continuous addition of fertilizer and manure in this layer. Kolambe (1992) also reported similar results for 21 swell-shrink soils of Maharashtra.

Dongale (1993) studied forms of phosphorus and their distribution in eight profiles of lateritic soils and concluded total P varied from 250 to 800 ppm. Soils of Kudal, Math and Nirvade profiles are derived from granite and gneiss and low organic carbon content. Other are derived from basalt and maximum P content in surface layer which decreased with depth.

Patgiri and Dutta (1993) studied the forms and distribution of P in some tea growing soils and concluded that total P content varied from 810 to 1162 ppm. Total P have highly significant positive correlation (r=0.65**) between organic carbon and total P suggested that organic matter contributed towards accumulation of total P in these soils.

Singh *et al.* (2003) studied on phosphorus fractions and their relationship to weathering indices of Vertisols and reported that mean total P content was 276.3 and 252.3 mg kg^{-1} in vertisols of Taswaria sodic and Taswaria series were the lowest with a mean content of 184.2 and 196.4 mg kg^{-1}, respectively. Vertisols of Kota, Chambal and Aklera series contained total phosphorus between 205 and 226 mg kg^{-1}. A higher total P in vertisols of Taswaria and Taswaria sodic series compared to the remaining soil series studied was partially attributed to the proportionate increase in Ca-P and organic P.

3. MATERIAL AND METHODS

The present investigation entitled "Effect of water soluble fertilizers through drip fertigation on yield of summer okra, nutrient uptake, nutrient availability and P fractions in Inceptisol." was carried out at the experimental farm of Inter-Faculty Department of Irrigation Water Management, Mahatma Phule Krishi Vidyapeeth, Rahuri during *summer* season of the year 2018-19. The details of materials used and methods adopted while conducting the experiment are described in this chapter.

3.1 Experimental materials

3.1.1 Experimental site

The experiment was conducted at Experimental Farm of Inter Faculty Department of Irrigation Water Management, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri (Maharashtra).

3.1.2 Climatic condition

3.1.2.1 General

Geographically the central campus of Mahatma Phule Krishi Vidyapeeth, Rahuri (MS) is situated in between 19^{0}47' and 19^{0}57' N latitudes and between 74^{0}32' and 74^{0}32' E longitudes. The altitude varies from 495 to 565 m above the mean sea level. This tract lying on the eastern side of Western Ghat and falls under rain shadow areas.

Climatically the central campus falls in semi-arid zone with the annual rainfall varying from 307 to 619 mm, the average annual rainfall being 520 mm. However, the rainfall is erratic and ill distributed, mostly concentrated during the monsoon months from June to September with 15-45 rainy days. Most of the rainfall is generally received from South West Monsoon. Agro-climatically the area falls in drought prone area of Maharashtra state facing drought frequently.

3.1.2.2 Nature of season during experimental period

The meteorological data on important weather parameters recorded during the crop growth period at the meteorological observatory of the Central Campus Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri, (M.S.) are presented in table 3.1 and Fig. 3.1. The mean maximum temperatures during experimentation period ranged between 31.9 to 41.2^{0}C, while mean minimum temperatures ranged between 13 to 26.9^{0}C. The relative humidity during morning and evening ranged from 59 and 37 per cent, respectively. The wind velocity ranged between 0.8 and 8.3 km hour^{-1}. Maximum weekly rainfall 7.0 mm occurred in 23rd meteorological week during the harvesting stage of crop growth.

Table 3.1. Metrological data during crop growth period in 2018-2019

Meteorological week	Date	Temperature (^{0}C)		Relative humidity (%)		Wind speed (km hr^{-1})	Rainfall (mm)
		Max.	Min.	RH I	RH II		
February, 2019							
8	19-25	34.6	15.9	50	24	0.8	0.00
9	26-4	31.9	13	47	20	1.4	0.00
March, 2019							
10	5-11	33.3	14.1	45	20	0.9	0.00
11	12-18	35.5	15.9	51	16	0.9	0.00
12	19-25	36.4	16.1	46	15	1.6	0.00
13	26-1	39.3	18.8	40	13	1.6	0.00
April, 2019							
14	2-8	39.7	19.9	38	14	2.5	0.00
15	9-15	40.4	21.2	35	13	2.1	0.00
16	16-22	37.1	19.2	45	19	2.7	4.4
17	23-29	41.2	20.7	37	16	2.5	0.00
18	30-6	39.1	20.7	37	16	4.2	0.00
May, 2019							
19	7-13	39.3	21.7	44	17	3.3	0.00
20	14-20	40.0	21.8	34	14	4.6	0.00
21	21-27	41.2	25.6	38	16	4.4	0.00
22	28-03	41.1	23.5	39	19	5.4	0.00
June, 2019							
23	7-13	39.1	26.9	51	30	5.4	7.0
24	14-20	37.0	24.9	59	35	8.3	0.4

3.1.3 Soil

The soil of the experimental site was uniform and leveled. The soil was well drained with 70 cm depth. In order to study the physio-chemical properties of soil, a composite soil sample from 0-45 cm soil layer was collected prior to planting and analyzed for physical and chemical properties. The relevant data on the physical and chemical properties of the experimental site (Table 3.2) along with the analytical methods used are presented in Table 3.2.

Table 3.2. Soil Physical and chemical characteristics of experimental site

Sr. No	Characteristics	Composition	Method used	Reference(s)
I	**Physical properties**			
1.	Coarse sand (%)	10.0	International pipette method	Piper (1966)
2.	Fine sand (%)	13.4		
3.	Silt (%)	30.1		
4.	Clay (%)	45.4		
5.	Textural class	Silty clay		
II.	**Soil moisture constants**			
1.	Field capacity (%)	39.1	Pressure plate apparatus	Richards (1947)
2.	Permanent wilting point (%)	17.1	Pressure membrane apparatus	Richards (1947)
3.	Bulk density (Mg m^{-3})	1.2	Core sampler	Dastane (1972)
4.	Infiltration rate (cm h^{-1})	4.1	Double ring infiltrometer	Klute (1986)
5.	Available soil moisture (%)	22.0	Derived (FC-PWP)	
III	**Soil Chemical properties**			
1.	pH (1:2.5)	8.15	Potentiometer	Piper (1966)
2.	EC (dSm^{-1})	0.39	Conductometer	Jackson (1973)
3	Available N (kg ha^{-1})	165.0	Alkaline permanganate	Subbiah and Asija (1956)
4.	Available P (kg ha^{-1})	18.2	0.5 M $NaHCO_3$ (pH 8.5)	Watanabe and Olsen (1965)
5.	Available K (kg ha^{-1})	472.5	*N* N NH_4OAc	Hanway and Heidal (1967)
IV	**Plant analysis**	**Method**	**Reference**	
1.	Preparation of acid extract from plant sample	Binary mixture of H_2SO_4+H_2O_2 (1:1)	Parkinson and Allen (1975)	
2.	Total N (%)	Microkjeldahl method	Jackson (1973)	
3.	Total P (%)	Vanadomolybdate phosphoric acid yellow colour	Jackson (1973)	
4.	Total K (%)	Flame photometer	Jackson (1973)	
VI	**Forms of Phosphorus**			
1.	Available P	Olsen P (0.5 M $NaHCO_3$, pH- 8.5)	Watanabe and Olsen (1965)	
2.	Organic P fractions (Saloid-P, Al-P, Fe-P, Ca-P, Occluded-P, Red- P)	Modified method of Chang and Jackson	Peterson and Corey (1966)	
3.	Total P	$HClO_4$ digestion	Jackson (1967)	

3.1.4 Water source

The source of water for the experimental plot was a tube well installed at farm with a 5 HP submersible pump. The water from tube well was stored in 40,000 lit capacity tank. The water storage tank was used for irrigation purpose throughout the study.

3.1.5 Cropping history of experimental plot

The cropping history of experimental field for previous three years is presented in Table 3.3.

Table 3.3 Cropping history of experimental field

Year	*Kharif*	*Rabi*	*Summer*
2016-17	Fallow	Soyabean	Fallow
2017-18	Fallow	Fallow	Okra
2018-19	Fallow	Soybean	Okra

3.2 Methods

3.2.1 Experimental Details

The experiment consisting of nine treatment combinations based on sources and level of fertilizers. The plan of experiment layout is presented in Fig. 3.2

The details of experiment are listed below,

1. Crop : Okra
2. Variety : Phule-Vimukta
3. Season : *Summer*, 2019
4. Date of sowing : 25 February, 2019
5. Spacing : 0.30 m × 0.15 m (4 lines per BBF of 1.20 m top and 1.50 m bottom)
6. Design : RBD
7. Number of treatments : 9
8. Number of replication : 3
9. Fertilizer dose : 100:50:50 N: P_2O_5: K_2O kg ha^{-1} and FYM @20 t ha^{-1}.
10. Gross plot size : 4.50 m x 9.00 m
11. Irrigation methods : 1. Drip irrigation – Alternate day based on (ETc)
    2. Surface irrigation -70 mm water at 70 mm CPE

3.2.2 Treatment Details

Following treatments were included in the study

T_1 - DI with 100 % RDF through fertigation as per schedule

T_2 - DI with 80 % RDF through fertigation as per schedule

T_3 - DI with 60 % RDF through fertigation as per schedule

T_4 - DI with 100 % RD of CF (N and K-drip and P - soil)

T_5 - DI with 100 % RD of CF (Soil)

T_6 - DI with 100 % RDF through fertigation in 7 equal weekly splits

T_7 - DI with application of fertilizer as per soil test values (125:50:25 N:P:K kg ha^{-1})

T_8 - DI with no fertigation

T_9 - SI with 100 % RD of conventional fertilizer (CF)

(CF- Conventional fertilizer, RDF- Recommended dose of fertilizer, DI- Drip Irrigation, SI- Surface Irrigation)

3.2.3 Details of fertilizers application

3.2.3.1 Sources of fertilizers

The sources of water soluble fertilizer (WSF) was urea (46 % N), urea phosphate (UP, 17:44:00). Conventional fertilizers as urea, single superphosphate (0:16:0) and muriate of potash (0:0:60) were used in surface irrigation.

3.2.3.2 Water soluble fertilizer schedule

Water soluble fertilizers were applied in treatments T_1, T_2, T_3 and T_7 as per schedule given in Table 3.5.

Table 3.4 Fertilizer schedules for okra

Per cent of nutrients applied to okra in 12 weekly splits

Crop Stage	Duration in day	Nutrients					
		%			kg ha^{-1}		
		N	P	K	N	P	K
Development Stage	1-21 (3 week)	25	30	20	25	15	10
Flowering Stage	22-42 (3 week)	35	40	30	35	20	15
Fruit Set	43-63 (3 week)	25	25	30	25	12.5	15
Fruit Picking	64-84 (3 week)	15	5	20	15	2.5	10
Total		**100**	**100**	**100**	**100**	**50**	**50**

Table 3.5. Proportion of nutrients applied in weekly splits (g /plot)

Treatment		Splits											
		1 to 3			4 to 6			7 to 9			10 to 12		
T_1	Urea	56.3	56.3	56.3	80.0	80.0	80.0	59.0	59.0	59.0	41.2	41.2	41.2
	UP	46.0	46.0	46.0	61.3	61.3	61.3	38.3	38.3	38.3	7.7	7.7	7.7
	SOP	27	27	27	40.5	40.5	40.5	40.5	40.5	40.5	27.0	27.0	27.0
T_2	Urea	45.1	45.1	45.1	64.0	64.0	64.0	47.3	47.3	47.3	32.9	32.9	32.9
	UP	36.8	36.8	36.8	49.1	49.1	49.1	30.7	30.7	30.7	6.1	6.1	6.1
	SOP	21.6	21.6	21.6	32.4	32.4	32.4	32.4	32.4	32.4	21.6	21.6	21.6
T_3	Urea	33.8	33.8	33.8	48.0	48.0	48.0	35.5	35.5	35.5	24.7	24.7	24.7
	UP	27.6	27.6	27.6	36.8	36.8	36.8	23.0	23.0	23.0	4.6	4.6	4.6
	SOP	16.3	16.3	16.3	24.3	24.3	24.3	24.3	24.3	24.3	16.2	16.2	16.2
T_4	Urea	73.3 g / split (12 splits)											
	SSP	1265.6 g / plot											
	MOP	16.8 g /split (12 splits)											
T_5	Urea	440.2 g as a basal dose and 50% N (146.7 g urea was applied each at 30, 45, 60 days after sowing)											
	SSP	1265.6 g / plot											
	MOP	337.5 g / plot											
T_6	Urea	101.5	101.5	101.5	101.5	101.5	101.5	101.5					
	UP	65.7	65.7	65.7	65.7	65.7	65.7	65.7					
	SOP	57.8	57.8	57.8	57.8	57.8	57.8	57.8					
T_7	Urea	74.7	74.7	74.7	105.7	105.7	105.7	77.5	77.5	77.5	52.2	52.2	52.2
	UP	46.0	46.0	46.0	61.3	61.3	61.3	38.3	38.3	38.3	7.7	7.7	7.7
	SOP	13.5	13.5	13.5	20.2	20.2	20.2	40.5	40.5	40.5	13.5	13.5	13.5
T_8	No fertilizer												
T_9	Urea	440.21 g as a basal dose and 50% N (146.7 g urea was applied each at 30, 45, 60 days after sowing)											
	SSP	1265.6 g / plot											
	MOP	337.5 g / plot											

3.2.3.3 Conventional fertilizers

In treatment T_4, total dose of phosphorus applied as basal dose and N and K was applied through drip as per schedule. In treatment T_5 and T_9, 50 % nitrogen and 100 % dose of phosphorus and potassium was applied as a basal dose and 50 % nitrogen was applied in 3 splits at 30, 45 and 60 days after sowing.

3.2.3.4 Cultural operations

Cultural operations like gap filling and weeding were carried out as recommended practice for normal cultivation.

3.2.3.5 Fertilizers

The straight fertilizers *viz*., Urea, single superphosphate and muriate of potash containing 46.4 per cent N, 16 per cent P_2O_5 and 60 per cent K_2O, respectively were used for application. The recommended fertilizers dose of 100 kg N, 50 kg P_2O_5 and 50 kg K_2O ha^{-1} were given.

3.2.4 Forms of soil phosphorus

Fractions of phosphorus are divided into three active fractions and two relatively inactive fractions. The active fractions are calcium phosphate, aluminium phosphate and iron phosphate, while inactive fractions include reductant soluble and occluded-P. Calcium P is present as discrete particles whereas Aluminium-P and Iron-P occur as films and/or adsorbed on clay or silt surfaces. The occluded P consists of Fe-P and Al-P fractions surrounded by an inert coat of another material that prevents the reaction of these phosphates with the soil solution. Reductant soluble forms occur with an inert material that may be partially or totally dissolved under anaerobic conditions. Phosphorus fractions were determined as outlined by Peterson and Corey (1966).

The original method employed by Chang and Jackson (1958) were used with few modifications suggested by Peterson and Corey (1966) and which are described here in brief.

Each of the P fractions was extracted from 1 g soil (<0.15mm) by extracting it successively with different extractants, developing colour by using acid molybdate and reducing agent and colour intensity measured on Spectrophotometer (Spectronic-20). The details of flow-scheme followed were as below:

i. Saloid bound phosphorus (Sal-P)

One gram of soil (< 0.15mm) extracted with 1 N NH_4Cl and P content in extract was estimated by chlorostannous reduced molybdo-phosphoric blue colour method, in sulphuric acid system.

ii. Aluminium bound phosphorus (Al-P)

To the soil previously extracted with NH_4Cl, was again extracted with 0.5 N NH_4F (pH 8.2) and the P in the extract was estimated by chlorostannous reduced molybdo-phosphoric blue colour method, in hydrochloric acid system.

iii. Iron bound phosphorus (Fe-P)

The residue from the first step (Sal-P) was shaken with 0.1 N NaOH solution for 17 hours so as to extract Fe-P. Phosphorus in the extract was determined by chlorostannous reduced molybdo-phosphoric blue colour method, in sulphuric acid system.

iv. Reductant soluble phosphorus (Red-P)

The soil was suspended in 0.3 M sodium citrate solution (tri basic salt) and shaken for 15 minutes with 0.5 g sodium dithonite. The reductant soluble P was estimated by chlorostannous reduced molybdo-phosphoric blue colour method, in sulphuric acid system. After estimation of Red-P, the soil residue left was treated with 0.25 ml 0.1 M NaOH and shaken for one hour. After centrifugation, a supernatant solution was used for the determination of Occluded-P by employing chlorostannous reduced molybdo-phosphoric blue colour method, in sulphuric acid system.

v. Calcium phosphorus (Ca-P)

The residue from previous (Occl-P) extraction was washed with saturated NaCl solution and suspended with 0.5 N H_2SO_4 and the phosphorus was estimated by chlorostannous reduced molybdo-phosphoric blue colour method, in sulphuric acid system.

vi. Organic phosphorus (Org-P)

This was obtained by subtracting the total inorganic phosphorus (summing up of all the mineral fractions) from total phosphorus in soil.

vii. Total phosphorus (Total P)

One gram of 0.5 mm sieved soil was weighed and transferred to a 300 ml platinum crucible and 30 ml of 60 per cent $HClO_4$ was added and digestion was carried out on sand bath at 130°C till the dense fumes of $HClO_4$ evolved. When digestion was completed, the platinum crucible was removed and cooled. The 50 ml of distilled water was added to the flask and solution was filtered into a 100 ml volumetric flask and volume was made with distilled water. An aliquot from this was used for estimation of total P by using vanodomolybdo-phosphoric acid reagent and the intensity of yellow colour was read at 470 nm spectro-photometer (Jackson, 1967).

3.2.5 Schedule of cultural operations

Various cultural operations carried out in the experimental field during crop season of the year 2018-2019 are presented in Table.3.6.

Table 3.6. Details of cultural operation

Sr. No.	Name of operation	Frequency	Date
1.	Ploughing	1	28/12/2018
2.	Harrowing	1	18/02/2019
3.	Marking	1	24/02/2019
4.	Preparation of layout	1	24/02/2019
5.	Sowing of seeds	1	25/02/2019
6.	Irrigations		26/02/2019
7.	Fertilizer application as basal dose	1	26/02/2019
8.	Gap filling	1	14/03/2019
9.	Weeding	2	19/03/2019, 10/04/2019
10.	Top dressing of urea (30, 45 and 60 DAS)	3	27/03/2018, 12/04/2018, 27/04/2018
11.	Sprayings	5	26/03/2019, 09/04/2019 15/04/2019, 03/05/2019 16/05/2019
12.	Number of picking 1) First picking 2) Last picking	14 - -	 18/04/2019 18/06/2019

3.2.6 Scheduling of irrigation

Drip irrigation system

In drip irrigation treatments, the irrigation scheduling was done on the basis of pan evaporation approach. Irrigation was scheduled on alternate days.

3.2.7 Irrigation systems

3.2.7.1 Drip irrigation set up

The components of drip irrigation system such as suction pipe, pumping unit and delivery pipes were connected to main, sub mains, manifolds, laterals and emitters. The central head unit comprised of sand filter, screen filter, back flush assembly, electric motor, pump set, control valve, bypass valve, pressure gauges and fertilizer tank.

3.2.7.2 Depth of irrigation

Irrigation was applied by using FAO-56 recommended climatological Method. Crop water requirement (Etc) estimated by Phule Jal Mobile app developed by Department of irrigation and drainage Engineering MPKV, Rahuri. The ETo was estimated by using modified panman formula embedded in Phule Jal app.

The depth of irrigation water to be applied was calculated using the formula

$$ETc = Kc \times ETo \quad \text{..... (3.1)}$$

Where,

ET_c = Evapo-transpiration of crop (mm)

K_C = Crop coefficient (as per crop growth stages) is given in Table 3.8

ETo = Reference evapotranspiration (mm)

Table 3.7. The details of drip irrigation system

Sr. No.	Particular	Size/Specifications
1.	Type of main and sub main	Poly-vinyl chloride (PVC)
2.	Type of laterals	Linear Low Density Poly ethylene LLDPE
3.	Size of main	75 mm
4.	Size of sub main	63 mm
5.	Size of laterals	16 mm
6.	Type of dripper	Inline dripper
7.	Discharge of emitter	4 lph
8.	Number of laterals /treatments	3
9.	Spacing between emitters	0.50 m
10.	Spacing between laterals	1.05 m

Table 3.8 Crop coefficients for okra crop

Growth stage	Crop coefficient factor	Crop duration days
Initial stage	0.7	0-35
Development stage	0.9	30-60
Maturity stage	1.02	61-90
End stage	0.96	95-120

The volume of water to be applied for growing period through drip was worked out with following formula (Allen *et al.*, 1998).

$$V = Etc \times \text{Plot area} \quad \text{..... (3.2)}$$

Where,

V = Volume of water per two days in liters

ETc = Crop evapotranspiration

3.2.6.3 Operation time of drip irrigation

The operation time of the system was calculated by,

$$T = Vg/q \quad \text{..... (3.3)}$$

Where,

T = Operating time of system, hrs.

Vg = Gross volume of water per two days in liter.

q = Emitter discharge, lph

3.2.6.4 Emission uniformity

The procedure suggested by Keller and Karmeli (1974) was used to determine the emission uniformity (EU) of the drip irrigation system.

$$Eu = 100 \times \frac{q_{min}}{q_{avg.}} + \frac{q_{avg.}}{q_{max.}} \times \frac{1}{2} \quad \text{… (3.4)}$$

Where,

q_{min} = Minimum discharge rate (lph)

$q_{avg.}$ = Average emitter flow rate (lph)

q_x = Average of the highest $1/8^{th}$ of emitter flow rate (lph)

3.2.6.5 Conventional Irrigation Method

The irrigation was given at 70 mm CPE.

Volume of water applied plot^{-1} was computed by using equation.

$$V = A \times D \qquad \text{...... (3.5)}$$

Where,

V = Volume of water applied (lit.)

A = Area of plot

D = Depth of water (mm) i.e. 70 mm

Depth of irrigation water irrigation^{-1} was determined with the help of moisture content.

D = FC- PWP x root zone depth x BD/ 100

FC = Field capacity

PWP = Permanent wilting point

BD = Bulk density

Root zone depth = 25 cm

3.2.7 Water use efficiency (WUE)

Water use efficiency (WUE) is defined as the ratio of yield of marketable produce of the crop and the amount of total use water required for crop growing. The water use efficiency was thus, worked out by the formula.

$$WUE = \frac{Y}{WU} \qquad \text{..... (3.6)}$$

Where,

WUE = Water use efficiency (kg ha^{-1} mm)

Y = Marketable yield per unit area (kg ha^{-1})

WU = Total water use (mm)

3.2.8 Plant protection measures

Plant protection schedule consists of various pesticides and insecticides for the control of pests and diseases. The plots were kept free of weeds by hand weeding. The details of spray schedule for control of pest and diseases are given in Table 3.9.

Table 3.9 Plant protection measures

Date	Spraying solution	Pest and disease
26.03.2019	5 g Thiamethoxam in 10 L of water	Aphids, Jassids, Whitefly
09.04.2019	20 g Acetamiprid 20 % SP in 10 L of water	Aphids, Whitefly
15.04.2019	Wettable sulphur 0.25 %	Fungal diseases
03.05.2019	6 ml Lamda Cyhalothrin in 10 L of water	Caterpillar
16.05.2019	8 ml Deltamethrin + 20 ml Quinolphos in 10 L of water	Fruit borer

3.3 Biometric observations

3.3.1 Sampling technique

The various biometric observations were recorded on five randomly selected okra plants from each treatment and replication. The sample plants were identified by fixing bamboo pegs near the plants. The details of observations recorded on the growth and yield attributes of okra during the course of investigation are presented in Table 3.10.

3.3.2 Growth studies

3.3.2.1 Growth observation

3.3.2.2 Height of the plant

The height of five labeled plants was recorded at 30, 60, 90 DAS and at last harvest. The plant height was measured from ground level to tip of the plant and the mean value was computed and expressed in cm.

3.3.2.3 Number of leaves plant^{-1}

The number of fully opened green leaves per plant was recorded at 30 days intervals from sowing up to harvest (30, 60, 90 DAS and at last harvest).

3.3.2.4 Length of fruits plant^{-1}

The length of fruits of five labeled plants was recorded at 30, 60, 90 DAS and at last harvest. The length was measured as the distance from the fruit cap scar at the base to the tip end of the pod and expressed in cm.

3.3.2.5 Chlorophyll content of okra

The chlorophyll content of five labeled plants was recorded at 30, 60, 90 DAS and at last harvest. The chlorophyll content was measured by spectrophotometer and expressed in µmol m^{-2}.

3.3.2.6 Days to 50 % flowering

The plots were visited daily after the appearance of first flower. Occurrence of flowers in each plot was taken as date of 50 % flowering. After sowing, number of days taken as date of 50 % flowering was calculated.

3.3.2.7 Days to fruit initiation

When five labeled plants started developing fruits, the stage was taken as the date of fruit initiation stage and the numbers of days from sowing to this stage were recorded.

Table 3.10 Schedule of biometric observations

Observation	**Time of observation**	**No of plants selected**
Growth observations		
Plant height (cm)	At 30, 60, 90 DAS and at last harvest	5 labelled plants per plot
Number of leaves $plant^{-1}$	At 30, 60, 90 DAS and harvest	5 labelled plants per plot
Number of fruits $plant^{-1}$	At each picking	5 labelled plants per plot
Length of fruits	60, 90 DAS and at last harvest	5 labelled plants per plot
Weight of fruits $plant^{-1}$ (kg)	At each picking	5 labelled plants per plot
Chlorophyll content	At 30, 60, 90 DAS and at last harvest	5 labelled plants per plot
Days to fruit initiation	No. of days required for fruit initiation	All plants in the plot
Days to fruit maturity	No. of days required for 1st picking	All plants in the plot

3.3.2.8 Days to fruit maturity

Days to fruit maturity was recorded at the time of first picking of the five labeled plants in each plot.

3.4 Micrometeorological observations

The physiological parameters viz. Photosynthetic rate, transpiration rate, stomatal conductance, stomatal resistance and leaf temperature were recorded periodically at an interval of 30 days after planting by using IRGA (Infra Red Gas Analyzer) model LICOR-6400 x T from each plot, the measurements were made at mid day, between 11:00 and 13:00 eastern day time (1400–1800 m mol $m^{-2}s^{-1}$), on top fully expanded leaf blades.

3.5 Yield and yield contributing characters

3.5.1.1 Number of fruits plant^{-1}

The mature fruits from five labeled plants were harvested and counted at each picking and summed up to obtained the total number of fruits per plant.

At each picking, number of fruits was counted and number of fruits per plant was calculated by following formula.

$$\text{Average number of fruits plant}^{-1} = \frac{\text{Total number of fruits}}{\text{Number of plants}} \quad \text{.... (3.7)}$$

3.5.1.2 Weight of fruits plant^{-1}

At each picking treatment wise okra fruits from labeled plants were harvested separately and recorded weight then obtained weight of fruit plant^{-1} by summing of all the picking and expressed in kilogram.

$$\text{Average weight of fruits plant}^{-1} = \frac{\text{Total weight of fruits}}{\text{Number of plants}} \quad \text{.... (3.8)}$$

3.5.1.3 Yield (t ha^{-1})

Fruits of okra were harvested and the total weight of fruits per plot was calculated and then calculated on hectare basis.

3.6 Economic analysis

3.6.1 Seasonal cost

Seasonal cost was worked out in each treatment. The variable cost includes paid out cost on hired human labour, machine labour, seeds, fertilizers, water charges, supervision charges and interest on working capital.

3.6.2 Net seasonal income

Net seasonal income was worked out by subtracting the cost of production from the gross returns for each treatment.

3.6.3 Benefit: cost ratio

The benefit: cost ratio was worked out by dividing the gross monetary returns by cost of production for each treatment under study. The benefit: cost ratio was computed as per following formula

$$\text{Benefit: cost ratio} = \frac{\text{Gross income (Rs. ha}^{-1}\text{)}}{\text{Total cost of cultivation (Rs. ha}^{-1}\text{)}} \quad \ldots\ldots (3.9)$$

3.6.4 Net extra income over control

Net extra income over control (Rs. ha^{-1}) as influenced by different treatments was calculated by subtracting the corresponding value of the net seasonal income from the value of net seasonal income of control treatment.

3.7 Sampling technique

3.7.1 Soil sampling

The soil samples were collected at 30, 60, 90 DAS and at last harvest of crop and collected soil samples were dried in shade, ground in mortar and pestle and passed through 2 mm sieve. These soil samples were used for further analysis.

3.7.2 Plant sampling

Periodical plant sampling was done at 30, 60, 90 DAS and at last harvest. The plant sampling was carried out by random selection of plant from net plots periodically. The collected plant samples were washed with deionised water, dried in diffused sunlight and chopped in small pieces, dried in oven at 65^{0}C till constant weight then grinded in stainless steel willeymilley. These processed samples were used for estimation nutrient concentration by adapting standard analytical method (Table 3.2).

3.8 Methods of analysis

3.8.1 Soil analysis

Soil samples were collected before transplanting of okra crop and analysed for available N, P and K content. The methods used for soil analysis are shown in Table 3.2.

3.8.2 Nutrient uptake

The uptake of major nutrients was worked out by multiplying dry matter to N, P and K concentration at different growth stages of crop by using the following equation.

$$\text{Uptake (kg ha}^{-1}\text{)} = \frac{\text{Total dry matter (kg ha}^{-1}\text{) x \% concentration of element}}{100} \quad \ldots(3.10)$$

3.8.3 Nutrient use efficiency

Various fertigation levels under different irrigation methods were evaluated to assess the effective utilization of fertilizers. The evaluation was expressed as crop production and unit weight of fertilizer applied through fertigation. The following method was used to estimate Nutrient use efficiency (NUE).

$$\text{NUE} = \frac{\text{Yield in treatment (kg ha}^{-1}\text{)} - \text{Yield in no fertilizer treatment (kg ha}^{-1}\text{)}}{\text{Nutrients applied (kg ha}^{-1}\text{)}} \quad \ldots\ldots (3.11)$$

3.8.4 Net profit /mm of water

The net profit / mm of water were worked out by dividing the net monetary returns by water used (mm) in each treatment under study. The net profit / mm of water was computed as per following Formula:

$$\text{Net profit/mm of water} = \frac{\text{Net monetary returns (Rs ha}^{-1}\text{)}}{\text{Water used (mm)}} \quad \ldots\ldots (3.12)$$

3.8.5 Statistical analysis

For statistical analysis, a standard method of Analysis of variance was used for analyzing the data for RBD design. The ‘F’ test of significance was used for testing the null hypothesis and appropriate standard error (SE) for each treatment effect were worked out; wherever the difference was significant, the critical difference (C.D.) at 5 percentage level of significance (Panse and Sukhatme, 1985).

4. RESULTS AND DISCUSSION

The experiment entitled "Effect of water soluble fertilizers through drip fertigation on yield of summer okra, nutrient uptake, nutrient availability and P fractions in Inceptisol." was conducted during the *summer* season of the year 2018-19, at Research Farm of Inter faculty Department of Irrigation Water Management, Post Graduate Institute Mahatma Phule Krishi Vidyapeeth Rahuri, Dist. Ahmednagar. The observations recorded during the investigation were statistically analyzed and results obtained are discussed in this chapter. This chapter is broadly categorized into following major topics.

4.1 Growth characters
4.2 Micrometeorological observations
4.3 Yield characters
4.4 Irrigation studies
4.5 Soil nutrient studies
4.6 P fraction studies
4.7 Plant nutrient uptake
4.8 Economical aspects

4.1 Growth parameters

Growth studies includes the biometric observations recorded for various growth characters viz., plant height, number of leaves, leaf area, days to 50 % flowering, days to fruit initiation, days to fruit maturity and dry matter content. The research findings on these aspects are presented in Table 4.1 to 4.6.

4.1.1 Plant height

The results indicated that plant height was found to be influenced significantly by fertigation treatments. The data regarding periodical plant height are presented in Table 4.1 and depicted in Fig. 4.1. The mean plant height was increased with increase in age of the crop and it was 27.62, 40.15, 81.17 and 104.54 cm at 30, 60, 90 DAS and at last harvest, respectively.

The drip irrigation with 100% RD of CF (T_5) recorded significantly maximum plant height (32.06 cm) at 30 DAS. However, it was at par with T_1, T_4, T_7 and T_9

treatments. The highest plant height in T_5 treatment might be due to application of basal dose of conventional fertilizers. Similar results were reported by Hooda *et al.* (1980).

The drip irrigation with application of fertilizer as per soil test values (T_7) recorded significantly maximum plant height (46.17, 87.38 and 111.86 cm) at 60, 90 DAS and at last harvest, respectively. However, it was at par with treatment T_1, T_7 and T_2. The treatment of DI with no fertigation (T_8, 15.48, 20.12, 60.24 and 79.30 cm) recorded minimum plant height at 30, 60, 90 DAS and at last harvest, respectively.

Table 4.1 Periodical plant height of okra as influenced by different treatments

Tr. No.	Treatment	Plant height (cm)			
		30 DAS	**60 DAS**	**90 DAS**	**At last harvest**
T_1	DI with 100% RDF through fertigation as per schedule	28.54	44.16	86.01	110.73
T_2	DI with 80% RDF through fertigation as per schedule	28.10	43.68	84.88	108.66
T_3	DI with 60% RDF through fertigation as per schedule	25.86	40.53	81.41	103.34
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	29.95	41.54	83.32	106.27
T_5	DI with 100% RD of CF (soil)	32.06	39.64	80.16	105.86
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	27.36	43.87	85.40	109.14
T_7	DI with application of fertilizer as per soil test values	30.30	46.17	87.38	111.86
T_8	DI with no fertigation	15.48	20.12	60.24	79.30
T_9	SI with 100% RD of CF	31.09	41.70	81.77	105.71
	S.Em.±	1.17	0.77	0.95	1.07
	CD at 5%	3.52	2.32	2.87	3.23
	General mean	**27.63**	**40.15**	**81.17**	**104.54**

The highest plant height in drip fertigated treatments might be due to effect of fertilization at proper growth stages and use of the water soluble fertilizers rather than conventional fertilizers. Similar results were reported by Firoz (2009) and Mohsen and Mohamed (2015) in okra crop.

4.1.2 Number of leaves

The results indicated that number of leaves plant^{-1} was found to be influenced significantly by fertigation treatments. The data regarding periodical number of leaves plant^{-1} are presented in Table 4.2 and depicted in Fig. 4.2. The mean number of leaves plant^{-1} were recorded as 11.06, 20.56, 30.76 and 28.64 cm at 30, 60, 90 DAS and at last harvest, respectively.

The number of leaves was increased with increase in age of the crop and maximum number of leaves was recorded at 90 DAS. The number of leaves decreased at harvest may be due to complete of life period of okra.

At 30 DAS, treatment T_5 (DI with 100% RD of CF) recorded significantly maximum number of leaves (14.53 cm). However, it was at par with T_9 (13.42 cm) and T_7 (12.25). The increase in number of leaves in T_5 and T_9 may be due to the application of conventional fertilizer after sowing as a basal dose.

Table 4.2 Periodical number of leaves of okra as influenced by different treatments

Tr. No.	Treatment	Number of leaves			
		30 DAS	**60 DAS**	**90 DAS**	**At last harvest**
T_1	DI with 100% RDF through fertigation as per schedule	11.75	23.19	33.53	31.11
T_2	DI with 80% RDF through fertigation as per schedule	11.52	22.53	32.66	30.23
T_3	DI with 60% RDF through fertigation as per schedule	8.02	16.46	26.66	25.26
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	10.84	20.82	32.20	27.97
T_5	DI with 100% RD of CF (soil)	14.53	19.82	30.21	28.64
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	10.03	21.46	32.01	30.12
T_7	DI with application of fertilizer as per soil test values	12.25	24.50	34.00	32.66
T_8	DI with no fertigation	7.21	15.25	24.13	22.43
T_9	SI with 100% RD of CF	13.42	21.05	31.46	29.35
	S.Em.±	0.77	1.22	0.96	1.32
	CD at 5%	2.30	3.67	2.87	3.98
	General mean	**11.06**	**20.56**	**30.76**	**28.64**

The significantly maximum number of leaves of (24.50, 34.00 and 32.66) were recorded for T_7 (Drip irrigation with application of fertilizer as per soil test values) at 60, 90 DAS and at last harvest, respectively. However, it was at par with treatment T_1, T_2, and T_6. The increase in number of leaves due to fertigation treatments may be attributed to the absorption of primary nutrients, which resulted in increased synthesis of carbohydrates, which are utilized in building up of new cells. Similar results were reported by Nair *et al.* (2017) in okra crop.

4.1.3 Length of fruits

The results indicated that the length of fruits was found to be influenced significantly by fertigation treatments. The data regarding length of fruits are presented in Table 4.3 and depicted in Fig. 4.3 The mean length of fruits was recorded as 8.79, 9.84 and 8.90 cm at 60, 90 DAS and at last harvest, respectively. The length of fruits was increased with increase in age of the crop.

Table 4.3 Length of fruits of okra as influenced by different treatments

Tr. No.	Treatments	Average length of okra fruits (cm)		
		60 DAP	90 DAP	At last harvest
T_1	DI with 100% RDF through fertigation as per schedule	9.60	11.55	10.89
T_2	DI with 80% RDF through fertigation as per schedule	9.52	10.76	9.56
T_3	DI with 60% RDF through fertigation as per schedule	7.62	8.21	7.94
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	8.92	10.05	9.03
T_5	DI with 100% RD of CF (soil)	8.24	9.34	8.64
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	9.51	10.60	9.51
T_7	DI with application of fertilizer as per soil test values	10.53	12.16	11.06
T_8	DI with no fertigation	7.23	7.55	6.39
T_9	SI with 100% RD of CF	8.02	8.38	7.12
	S.Em.±	0.61	0.60	0.47
	CD at 5%	1.83	1.82	1.46
	General mean	**8.79**	**9.84**	**8.90**

The drip irrigation with application of fertilizer as per soil test value (T_7) recorded significantly maximum length of fruits (10.53, 12.16 and 11.06 cm) at 60, 90 DAS and at last harvest, respectively. However, it was at par with treatment T_1, T_2 and T_6. This may be due to proper dose of fertigation to the soil. The treatment T_8 (7.23, 7.55 and 6.39 cm) recorded minimum length of fruit at all stages of crop growth. This may be due to lack of fertilization rendered to the soil.

The significantly highest length of fruits in fertigated treatments might be due to availability of sufficient moisture and uniform nutrient availability through WSF in root zone of the as per crop growth stages as compared to surface irrigation with 100% RD of CF (T_9) and drip irrigation with 100% RD of CF applied through soil (T_5).

Gowda *et al.* (2002) reported significant increase in fruit length with increase in levels of NPK. These results are in conformity with those reported by Sajjan *et al.* (2002).

4.4 Average chlorophyll content in okra as influenced by different treatments

The data regarding chlorophyll content of okra plants are presented in Table 4.4 and Fig.4.4. The results indicated that chlorophyll content of okra plant was found to be influenced significantly by fertigation treatments.

The mean chlorophyll content was recorded as 32.26, 38.53, 34.91 and 33.35 $\mu mol/m^2$ at 30, 60, 90 DAS and at last harvest, respectively. The data revealed that the treatment T_5 i.e. DI with 100% RD of CF showed maximum chlorophyll content at 30 DAS i.e. (43.12 $\mu mol/m^2$). However, it was at par with treatment T_9 (42.12 $\mu mol/m^2$). This is may be due to the application of conventional fertilizer after sowing as a basal dose.

The drip irrigation with application of fertilizer as per soil test value (T_7) recorded significantly maximum chlorophyll content (46.05, 42.12 and 38.46 $\mu mol/m^2$) at 60, 90 DAS and at last harvest, respectively. However, it was at par with treatment T_1 and T_2 at 60 DAS and at last harvest while at par with T_1 at 90 DAS.

Table 4.4 Average chlorophyll content in okra plants as influenced by different treatment

Tr. No.	Treatment	Chlorophyll Content (µmol/m^2)			
		30 DAS	**60 DAS**	**90 DAS**	**At last harvest**
T_1	DI with 100% RDF through fertigation as per schedule	32.84	45.24	41.18	37.88
T_2	DI with 80% RDF through fertigation as per schedule	31.56	44.23	39.78	37.12
T_3	DI with 60% RDF through fertigation as per schedule	28.23	35.14	29.56	27.56
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	31.20	35.56	34.94	32.61
T_5	DI with 100% RD of CF (soil)	43.12	35.30	33.81	30.15
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	30.02	38.05	35.60	33.06
T_7	DI with application of fertilizer as per soil test values	33.14	46.05	42.12	38.46
T_8	DI with no fertigation	27.15	32.01	25.64	23.64
T_9	SI with 100% RD of CF	42.12	35.23	31.64	30.70
	S.Em.±	0.51	0.69	0.67	0.60
	CD at 5%	1.55	2.09	2.02	1.80
	General mean	**33.26**	**38.53**	**34.91**	**33.35**

4.1.4.2 Days required for 50% flowering

The data regarding days required for 50 % flowering are presented in Table 4.5. The results indicated that the days required for 50 % flowering was found to be influenced significantly by fertigation treatments. The mean days required for 50 % flowering was recorded as 43.65. The data revealed that the treatment T_7 i.e. Drip irrigation with application of fertilizer as per soil test values (42.03 days) showed early 50 % flowering, followed by T_1 (42.31 days) and T_2 (43.01 days) and the treatment T_8 i.e. DI with no fertigation (45.02 days) recorded late 50 % flowering.

The early flower initiation in drip fertigated treatments might be due to effect of fertilization at proper growth stages and use of the water soluble fertilizers rather than conventional fertilizers. Similar results was reported by Mahendran *et al*. (2011) in okra crop.

4.1.4.3 Days required for fruit initiation

The data regarding days required for fruit initiation are presented in Table 4.5. The results indicated that the days required for fruit initiation was found to be influenced significantly by fertigation treatments. The data revealed that the treatment T_7 i.e. Drip irrigation with application of fertilizer as per soil test values (47.27 days) showed early fruit initiation, followed by T_1 (48.12 days) and T_2 (48.23 days) and the treatment T_8 i.e. DI with no fertigation (52.26 days) recorded late fruit initiation.

Table 4.5 Days to 50 % flowering, Days to fruit initiation and days to fruit maturity as influenced by different treatments

Tr. No.	Treatment	Days to 50% flowering (DAS)	Days to fruit initiation (DAS)	Days to fruit maturity (DAS)
T_1	DI with 100 % RDF through fertigation as per schedule	42.31	48.12	57.05
T_2	DI with 80 % RDF through fertigation as per schedule	43.01	48.23	57.21
T_3	DI with 60 % RDF through fertigation as per schedule	43.75	49.89	57.65
T_4	DI with 100 % RD of CF (N and K –drip and P- soil)	43.81	48.35	57.25
T_5	DI with 100 % RD of CF (soil)	44.36	49.03	57.33
T_6	DI with 100 % RDF through fertigation in 7 equal weekly splits	43.42	48.13	56.47
T_7	DI with application of fertilizer as per soil test values	42.03	47.27	55.77
T_8	DI with no fertigation	45.02	52.26	61.28
T_9	SI with 100% RD of CF	44.10	51.10	59.09
	S.Em.±	0.53	0.48	0.85
	CD at 5%	1.59	1.44	2.56
	General mean	**43.65**	**49.26**	**58.90**

The early fruit initiation in drip fertigated treatments might be due to effect of fertilization at proper growth stages and use of the water soluble fertilizers rather than conventional fertilizers. Similar results of early fruit initiation in okra were reported by Mahendran *et al*. (2011).

4.1.4.4 Days required for fruit maturity

The data regarding days required for fruit maturity are presented in Table 4.5. The results indicated that the days required for fruit maturity was found to be influenced significantly by fertigation treatments. The mean days required fruit maturity was recorded as 57.67 from the sowing of crop. The data revealed that the treatment T_7 i.e. Drip irrigation with application of fertilizer as per soil test values (55.77 days) showed early fruit maturity, followed by T_1 (57.05 days) and T_2 (57.21 days) and the treatment T_8 i.e. DI with no fertigation recorded late fruit maturity as 61.28 days. This may be due to lack of nutrition as no fertigation were applied.

The early fruit maturity in drip fertigated treatments might be due to effect of fertilization at proper growth stages and use of the water soluble fertilizers rather than conventional fertilizers.

4.1.4.5 Dry matter content

The data pertaining to dry matter accumulation (g plant^{-1}) are presented in Table 4.6 revealed significant differences in dry matter accumulation among the treatments. The mean dry matter content in okra was recorded as 3.09, 7.44, 18.49 and 20.66 g plant^{-1} at 30, 60, 90 DAS and at last harvest. The dry matter accumulation increased with increase in crop growth and highest dry matter accumulation was recorded at last harvest.

At 30 DAS, treatment T_5 (DI with 100% RD of CF) recorded significantly maximum dry matter accumulation (4.05 g plant^{-1}). However, it was at par with T_7 (3.86 g plant^{-1}), T_1 (3.81 g plant^{-1}) and T_9 (3.77 g plant^{-1}). Treatment T_8 i.e. (DI with no fertigation) recorded minimum dry matter accumulation (1.25 g plant^{-1}). The highest dry matter in T_5 might be due to application of CF as a basal dose.

At 60 DAS, DI with application of fertilizer as per soil test values (T_7) recorded significantly more dry matter accumulation (9.43 g plant^{-1}). However, it was at par with $T_{1,}$ $T_{2,}$ T_6 and T_4. Treatment T_8 recorded minimum dry matter accumulation of 4.08 g plant^{-1}. Similar trend of dry matter accumulation was observed at 90 DAS and at harvest. There was maximum accumulation of dry matter plant^{-1} in drip fertigation with water soluble fertilizer treatments at 60, 90 DAS and at harvest as compared to DI with 100% RD of CF (T_5) and surface irrigation (SI) with 100% RDF of CF (T_9). This may be due to the profused vegetative growth on account of optimum moisture and nutrient supply, in the rhizosphere during the okra crop at growth period. Almost similar results were obtained by Jamrey (2013) in okra crop.

Table 4.6 Dry matter accumulation in okra as influenced by different treatment

Tr. No.	Treatment	Dry matter (g plant^{-1})			
		30 DAS	60 DAS	90 DAS	At last harvest
T_1	DI with 100% RDF through fertigation as per schedule	3.81	9.31	19.86	23.49
T_2	DI with 80% RDF through fertigation as per schedule	3.30	8.70	19.67	22.32
T_3	DI with 60% RDF through fertigation as per schedule	1.52	5.21	17.30	18.55
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	2.80	8.13	19.13	21.23
T_5	DI with 100% RD of CF (soil)	4.05	7.65	18.56	20.48
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	3.51	8.42	19.46	21.73
T_7	DI with application of fertilizer as per soil test values	3.86	9.43	20.51	24.33
T_8	DI with no fertigation	1.25	4.08	13.61	13.76
T_9	SI with 100% RD of CF	3.77	6.11	18.34	20.09
	S.Em.±	0.35	0.53	0.61	1.06
	CD at 5%	1.05	1.61	1.84	3.17
	General mean	**3.09**	**7.44**	**18.49**	**20.66**

4.2 Micrometeorological observations

4.2.1 Photosynthetic rate

The data regarding the photosynthetic rate was found to be significantly influenced by periodical application of fertilizer at various critical growth stages. The data is presented in Table 4.7 and depicted in Fig. 4.5. The photosynthetic rate was significantly influenced by different treatments. The mean photosynthetic rate was recorded as 31.94, 35.71 and 29.95 µmol m^{-2} sec^{-1} at 30, 60 and 90 DAS, respectively.

The highest photosynthetic rate is observed in T_7 (36.47, 40.25 and 34.27 µmol m^{-2} sec^{-1}) at 30, 60 and 90 DAS, respectively while it is lowest in T_8 (27.60, 31.50 and 25.62 µmol m^{-2} sec^{-1}) at 30, 60 and 90 DAS, respectively. Kimball (1983) reported that there was enrichment of photosynthesis, growth and yield by increasing the concentration of CO_2 in many crop species.

4.2.2 Stomatal conductance

The data pertaining to mean stomatal conductance of okra as influenced by different treatments at all growth stages of okra are presented in Table 4.7. The mean stomatal conductance of okra plant was 0.84, 1.22 and 0.71 mmol m^{-2} s^{-1} at 30, 60 and 90 DAS, respectively.

Stomatal conductance is highest in T_7 i.e. 1.35, 1.93 and 1.07 mmol m^{-2} s^{-1} at 30, 60 and 90 DAS, respectively and it was at par with T_5 and lowest stomatal conductance was recorded in T_8 i.e. 0.43, 0.65 and 0.32 mmol m^{-2} s^{-1} at 30, 60 and 90 DAS, respectively (table 4.7). Collinson *et al.* (1997) reported the tendency of reduction in stomatal conductance under water stress condition. Hence, lower values were observed in surface irrigation treatments (T_9) as compared to drip irrigation treatments (T_1, T_2, T_5 and T_7).

4.2.3 Stomatal resistance

The stomatal resistance was influenced significantly due to fertigation treatments at 30, 60, 90 DAS and at last harvest. The mean stomatal resistance was recorded as 0.99, 1.22 and 0.89 μ mol m^{-2} s^{-1} at 30, 60 and 90 DAS, respectively.

The data is presented in Table 4.7 significantly higher stomatal resistance was recorded in T_5 [DI with 100 % RD of CF (soil)] i.e. (1.45, 1.71 and 1.3 μ mol m^{-2} s^{-1}) and lowest value was recorded in T_7 (0.57, 0.84 and 0.41 μ mol m^{-2} s^{-1}) at 30, 60 and 90 DAS. The lowest stomatal resistance in T_7 was due to the maximum nutrient availability to the crop which resulted in the better absorption of PAR for biomass production. Similar results were also reported by Singhadhupe *et al.* (2003).

4.2.4 Leaf temperature

The leaf temperature was influenced significantly due to fertigation treatments at 30, 60, 90 DAS and at last harvest. The mean leaf temperature was recorded as 30.87, 31.73 and 32.59 at 30, 60 and 90 DAS, respectively. The data are presented in Table 4.7 significantly lower leaf temperature was recorded in T_7 i.e. 28.36°C.

Table 4.7 Periodical micro meteorological data of okra

Tr. No.	Treatments	Photosynthetic rate (µ mol $CO_2 m^{-2} s^{-1}$)			Stomatal Conductance (µ mol $m^{-2} s^{-1}$)			Stomatal Resistance (µ mol $m^{-2} s^{-1}$)			Leaf Temperature (^0C)			Transpiration rate (µ mol $CO_2 m^{-2} s^{-1}$)		
		30 DAS	**60 DAS**	**90 DAS**	**30 DAS**	**60 DAS**	**90 DAS**	**30 DAS**	**60 DAS**	**90 DAS**	**30 DAS**	**60 DAS**	**90 DAS**	**30 DAS**	**60 DAS**	**90 DAS**
1	DI with 100% RDF through fertigation as per schedule	32.83	36.12	30.80	1.01	1.93	1.07	0.65	0.95	0.56	33.2	33.98	34.28	12.34	12.49	11.3
2	DI with 80% RDF through fertigation as per schedule	32.08	35.18	30.22	0.96	1.32	0.84	0.94	1.10	0.84	31.45	32.25	33.49	11.20	11.62	10.17
3	DI with 60% RDF through fertigation as per schedule	28.32	32.06	26.19	0.49	0.87	0.38	1.01	1.23	0.91	28.56	29.09	29.38	8.37	9.44	7.33
4	DI with 100% RD of CF (N and K –drip and P- soil)	31.13	35.19	29.32	0.73	1.01	0.61	1.15	1.41	1.05	30.40	31.37	32.46	10.63	11.71	9.61
5	DI with 100% RD of CF (soil)	34.36	38.44	32.14	1.06	1.51	0.98	0.90	1.05	0.83	31.71	32.53	33.78	13.19	14.26	12.30
6	DI with 100% RDF through fertigation in 7 equal weekly splits	31.49	35.27	29.44	0.68	0.97	0.71	1.32	1.63	1.21	32.13	33.42	34.20	10.42	11.43	9.25
7	DI with application of fertilizer as per soil test values	36.47	40.25	34.27	1.35	1.42	0.92	0.57	0.84	0.41	28.36	28.46	29.24	15.45	15.81	14.29
8	DI with no fertigation	27.60	31.50	25.62	0.43	0.65	0.32	0.93	1.07	0.83	32.01	33.25	34.18	6.17	7.29	5.30
9	SI with 100% RD of CF	33.25	37.43	31.56	0.82	1.29	0.55	1.45	1.71	1.32	30.05	31.29	32.37	14.11	15.28	13.35
	S.Em.±	0.58	0.64	0.66	0.01	0.1	0.03	0.01	0.02	0.02	0.6	0.18	0.5	0.52	0.54	0.42
	CD at 5%	1.76	1.92	1.98	0.03	0.32	0.09	0.04	0.08	0.06	1.8	0.56	1.51	1.57	1.64	1.28
	General mean	**31.94**	**35.71**	**29.95**	**0.84**	**1.22**	**0.71**	**0.99**	**1.22**	**0.89**	**30.87**	**31.73**	**32.59**	**11.32**	**12.15**	**10.32**

4.2.5 Transpirational rate

From the Table 4.7, it can be observed that the transpiration rate is increased from 30 DAS to 60 DAS and then decreases at 90 DAS and the harvesting stage for all the treatments. The transpirational rate at 90 DAS is lower even than the 30 DAS. The highest transpiration rate is observed for T_7 [DI with application of fertilizer as per soil teat values] i.e. 15.45, 15.81, and 14.29 µmol CO_2 $m^{-2}s^{-1}$ at 30, 60 and 90 DAS respectively. The lowest values were recorded for T_8 (DI with no fertigation) i.e. 6.17, 7.29 and 5.30 µmol CO_2 $m^{-2}s^{-1}$ at 30, 60 and 90 DAS respectively.

4.3 Yield and yield contributing characters of okra

4.3.1 Number of fruits plant^{-1}

The data regarding the average number of fruits plant^{-1} are presented in Table 4.8. and depicted in Fig. 4.6. The mean number of fruits plant^{-1} was recorded as 17.32. The significantly highest number of fruits plant^{-1} was recorded in treatment T_7 i.e. Drip irrigation with application of fertilizer as per soil test values (20.81); however, it was at par with T_1 (20.32), T_2 (19.22) and T_6 (19.60). Treatment T_8 (DI with no fertigation) recorded the lowest number of fruits plant^{-1} i.e. 8.30.

The drip irrigation with 100 % RDF through fertigation treatment showed significantly maximum number of fruits per plant. This might be due to maximum number leaves produced in these treatments; it is in agreement with findings of Khushwah *et al.* (2008), Zainullah (2010), Verma and Batra (2001) in okra crop.

4.3.2 Weight of fruits

The data regarding weight of fruits are presented in Table 4.8 and depicted in Fig. 4.7. The average weight of fruits was recorded as 163.65 g plant^{-1}. The weight of fruits plant^{-1} was recorded significantly highest for T_7 (182.24 g), however, it was at par with T_1 (181.80 g), T_2 (180.30 g) and T_6 (176.00). Treatment T_8 (DI with no fertigation) recorded the lowest weight of fruits plant^{-1} i.e. 87.72 g.

The weight of okra fruit itself is the function of photosynthesis by plant and its translocation efficiency. The photosynthetic productions in turn affected by all the growth parameters such as plant height and number of leaves which ultimately increased the number of fruits plant^{-1} and weight of fruits plant^{-1} in drip fertigated treatments.

The drip fertigation treatments showed significant effect over DI with soil application of conventional fertilizer (T_5) with almost 13.82 g increase in average weight of fruits plant^{-1}. This might be due to application of conventional fertilizer through soil as a basal dose which reduced the availability of nutrients at fruiting stage which was reflected in low uptake of nutrients and ultimately resulted into reduced average weight of fruits plant^{-1}. Similar result was reported by Jamrey (2013) in okra crop.

Table 4.8 Average number of fruits plant^{-1}, average weight of fruits plant^{-1} and yield of green fruits of okra as influenced by different treatments

Tr. No.	Treatment	Average number of fruits plant^{-1}	Average weight of fruits plant^{-1} (g)	Yield of green fruits (t ha^{-1})	Per cent increase in yield over T_5
T_1	DI with 100 % RDF through fertigation as per schedule	20.32	181.80	18.06	27.18
T_2	DI with 80 % RDF through fertigation as per schedule	19.60	180.30	16.95	19.36
T_3	DI with 60 % RDF through fertigation as per schedule	16.30	163.71	13.86	-
T_4	DI with 100 % RD of CF (N and K-drip and P- soil)	18.42	171.53	16.85	18.66
T_5	DI with 100 % RD of CF (soil)	15.20	168.42	14.20	-
T_6	DI with 100 % RDF through fertigation in 7 equal weekly splits	19.22	176.60	17.45	22.88
T_7	DI with application of fertilizer as per soil test values	20.81	182.24	19.55	37.67
T_8	DI with no fertigation	8.30	87.72	6.15	-
T_9	SI with 100% RD of CF	17.70	160.51	15.60	9.85
	S.Em.±	0.60	2.57	0.85	-
	CD at 5%	1.80	7.72	2.75	-
	General mean	**17.32**	**163.65**	**15.40**	**-**

4.3.3 Yield

The data regarding the yield of okra in tones ha^{-1} are presented in Table 4.8 depicted in Fig. 4.8. The average yield of green fruit was recorded as 15.40 t ha^{-1}. From the data, it was observed that drip irrigation with application of fertilizer as per soil test values T_7 recorded significantly maximum yield (19.55 t ha^{-1}) over DI with 100 %

RD of CF T_5 (14.20 t ha^{-1}). However, it was at par with T_1 (18.06 t ha^{-1}), T_6 (17.45 t ha^{-1}), T_2 (16.95 t ha^{-1}) and T_4 (16.85).

The drip with fertigation treatments showed significant effect over drip irrigation with 100 % RD of CF (T_5), almost 5.35 t ha^{-1} increases in yield of green fruits was recorded. This might be due to application of water soluble fertilizers as per soil test values in split doses resulted in higher yield due to uniform availability of nutrients throughout the growth stage as compare to the treatments receiving fertilizers through the soil. Similar results were reported by Patel and Rajput (2003) and Varughese *et al*. (2014)

4.4 Water use of okra

The average water requirement of okra under different irrigation methods was ranged from 617.3 – 914.9 mm. The drip method of irrigation resulted into lowest water use (617.3 mm) as compared to surface method of irrigation (914.9 mm) and thus resulted into 48.2 per cent water saving in drip irrigation system (Table 4.9). Water requirement in drip was very less as compared with the water requirement under conventional method of irrigation, because water was directly applied in root zone which increased water application efficiency and decreased water losses through percolation, infiltration, evaporation and losses of P and K by fixation in the soil (Jamrey, 2013).

4.4.1 Water use efficiency of okra

The treatment T_7 (DI with application of fertilizer as per soil test values) recorded significantly higher yield (19.55 t ha^{-1}) showing the readily availability of nutrients from water soluble fertilizers. However, the water use efficiency (WUE) can be increased either by increasing the numerator (crop yield) or by decreasing the denominator. The numerator, being plant production, depends on such plant factors as growth enhancement due to photosynthesis versus losses due to diseases and pests. Hence, water use efficiency can be influenced by such means as pest, disease control, availability and uptake of nutrients. The data presented in Table 4.9 and Fig. 4.9 revealed that maximum values of WUE was obtained in drip irrigation with application of fertilizer as per soil test values T_7 (31.67 kg ha^{-1} mm) followed by T_1 (29.26 kg ha^{-1} mm) and T_6 (28.27 kg ha^{-1}mm).

There was almost 48.2 per cent of water saving in drip irrigated treatments over the surface irrigated treatments. Similar results were reported by Punamhoro *et al.* (2003) and Mahendran *et al*. (2011) in okra crop.

Table 4.9. Water use of okra as influenced by fertigation

Tr. No.	Treatment	Total water applied (mm)	Yield of okra (t ha^{-1})	WUE (kg ha^{-1}mm)	Water saving over T_8 (%)
T_1	DI with 100% RDF through fertigation as per schedule	617.3	18.06	29.26	48.2
T_2	DI with 80% RDF through fertigation as per schedule	617.3	16.95	27.46	48.2
T_3	DI with 60% RDF through fertigation as per schedule	617.3	13.86	22.45	48.2
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	617.3	16.85	27.30	48.2
T_5	DI with 100% RD of CF (soil)	617.3	14.20	23.00	48.2
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	617.3	17.45	28.27	48.2
T_7	DI with application of fertilizer as per soil test values	617.3	19.55	31.67	48.2
T_8	DI with no fertigation	617.3	6.15	9.96	48.2
T_9	SI with 100% RD of CF	914.9	15.60	17.05	-

4.5 Periodical nutrient availability in soil

The periodical availability of N, P and K in soil was significantly influenced due to fertigation treatments as the fertilizers were applied in 12 weekly splits scheduled according to growth stages of okra crop. The maximum nutrient availability was observed at 60 DAS. The treatment T_7 recorded maximum availability of N and P (193.5 and 38.5 kg ha^{-1}) due to application of 125 % RDF whereas as maximum K availability (512 kg ha^{-1}) was recorded in T_1 treatment. The lowest N, P and K availability was observed in T_8 i.e. no fertigation treatment as 163.7, 15.7 and 469.4 kg ha^{-1} at 60 DAS.

4.5.1 Availability of nitrogen in soil

The nitrogen availability in the root zone soil of okra was found to be influenced by period and levels of fertilizers (Table 4.10 and Fig. 4.10). The average N availability in soil was 177.5, 181.1, 174.1 and 161.1 kg ha^{-1} at 30, 60, 90 DAS and at last harvest, respectively. The N availability increased with period from sowing to 60 DAS and thereafter decreased up to harvesting stage in all the treatments. The decreased N availability in soil after 60 DAS may be due to higher uptake of N by plants at fruiting stage. The level of fertilizer had influenced the N availability in soil up to some extent.

Table 4.10. Periodical nitrogen availability in soil as influenced by different treatments

Tr. No.	Treatment	Nitrogen availability (kg ha^{-1})				
		Initial	30 DAS	60 DAS	90 DAS	At last harvest
T_1	DI with 100% RDF through fertigation as per schedule	165.0	179.3	191.6	182.4	163.5
T_2	DI with 80% RDF through fertigation as per schedule	165.0	176.6	186.4	181.1	162.7
T_3	DI with 60% RDF through fertigation as per schedule	165.0	171.2	175.0	167.4	159.3
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	165.0	177.1	181.8	176.3	162.1
T_5	DI with 100% RD of CF (soil)	165.0	184.3	179.8	174.4	164.5
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	165.0	175.4	184.7	177.6	162.5
T_7	DI with application of fertilizer as per soil test values	165.0	186.5	193.5	185.1	167.1
T_8	DI with no fertigation	165.0	163.7	159.8	153.5	149.5
T_9	SI with 100% RD of CF	165.0	183.5	177.4	169.5	159.0
	S.Em.±	-	1.23	1.52	0.92	1.05
	CD at 5%	-	3.71	4.58	2.75	3.16
	General mean	**165.0**	**177.5**	**181.1**	**174.1**	**161.1**

At 30 DAS, the significantly highest nitrogen availability is recorded in DI with application of fertilizer as per soil test values T_7 (186.5 kg ha^{-1}), however it is at par with T_5 (184.3 kg ha^{-1}) and T_9 (181.5 kg ha^{-1}). The lowest N availability was recorded in T_8 treatment (163.7 kg ha^{-1}).

At 60 DAS, the significantly highest nitrogen availability is recorded in DI with application of fertilizer as per soil test values T_7 (193.5 kg ha^{-1}), however it is at par with T_1 (191.6 kg ha^{-1}). The lowest N availability was recorded in T_8 treatment (159.80 kg ha^{-1}).

The higher availability of N in drip fertigated treatments at 60 DAS was due to the application of water soluble fertilizers as per growth stages resulted in increased nutrient availability in root zone soil of okra. Similar trend of N availability were observed at 90 DAS and at last harvest. Almost similar result was reported by varughese *et al*. (2014) in okra crop.

The treatment T_7 where N was applied as per soil test values (125% of RDF) resulted into more availability of nitrogen in soil at last harvest followed by T_5 where 100% RD of conventional fertilizers were applied through soil.

4.5.2 Availability of phosphorus in soil

The phosphorus availability in the root zone soil was found to be influenced by period and levels of fertilizers (Table 4.11 and depicted in Fig. 4.11). The average P availability in soil was 23.9, 30.4, 19.9 and 15.3 kg ha^{-1} at 30, 60, 90 DAS and at last harvest, respectively. The P availability increased with period from sowing up to 60 DAS and there after decreased up to harvesting stage in all the treatments. The decreased P availability in soil after 60 DAS may be due to higher uptake of P by plants at fruiting stage. The level of fertilizers had influenced the P availability in soil up to some extent.

At 30 DAS, the significantly highest phosphorus availability is recorded in DI with 100 % RD of CF (T_5, 28.1 kg ha^{-1}); however, it is at par with T_9 (27.6 kg ha^{-1}) and T_4 (26.7 kg ha^{-1}). The lowest P availability was recorded in T_8 treatment (17.4 kg ha^{-1}).

At 60 DAS, the significantly highest phosphorus availability is recorded in DI with application of fertilizer as per soil test values T_7 (38.5 kg ha^{-1}); however, it is at par with T_1 (37.6 kg ha^{-1}), T_6 (35.7 kg ha^{-1}) and T_2 (34.9 kg ha^{-1}). The lowest P availability was recorded in T_8 treatment (15.7 kg ha^{-1}). This may be due to the no fertilizer application.

The higher availability of P in drip fertigated treatments at 60 DAS may be due to the application of water soluble fertilizers as per growth stages resumed in increased nutrient availability in root zone soil of okra. Similar trend of P availability was also observed at 90 DAS. Similar results were reported by Madhusoodana (2016) and Balsubramanian *et al*. (2000) in cotton crop.

Table 4.11. Periodical phosphorus availability in soil as influenced by different treatments

Tr. No.	Treatment	Phosphorus availability (kg ha^{-1})				
		Initial	30 DAS	60 DAS	90 DAS	At last harvest
T_1	DI with 100% RDF through fertigation as per schedule	18.2	25.4	37.6	23.5	16.1
T_2	DI with 80% RDF through fertigation as per schedule	18.2	24.7	34.9	22.6	15.7
T_3	DI with 60% RDF through fertigation as per schedule	18.2	18.6	28.3	14.7	13.1
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	18.2	26.7	31.5	21.6	16.5
T_5	DI with 100% RD of CF (soil)	18.2	28.1	31.6	21.1	17.8
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	18.2	22.7	35.7	22.5	16.4
T_7	DI with application of fertilizer as per soil test values	18.2	24.5	38.5	24.4	16.0
T_8	DI with no fertigation	18.2	17.4	15.7	13.4	10.8
T_9	SI with 100% RD of CF	18.2	27.6	20.4	15.7	15.8
	S.Em.$\pm$	-	0.70	1.23	0.91	0.53
	CD at 5%	-	2.10	3.69	2.75	1.60
	General mean	**18.2**	**23.9**	**30.4**	**19.9**	**15.3**

At last harvest, the significantly highest phosphorus availability is recorded in DI with 100 % RD of CF (T_5, 17.8 kg ha^{-1}), however it is at par with T_4 (16.50 kg ha^{-1}) and T_6 (16.40 kg ha^{-1}). The lowest P availability was recorded in T_8 i.e. no fertigation treatments (10.82 kg ha^{-1}). The T_5 where P was applied through soil resulted into more availability of phosphorus in soil at last harvest which may be due to less P uptake of okra as compared to fertigation treatments.

4.5.3 Availability of potassium in soil

The potassium availability in the root zone soil was found to be influenced by period and levels of fertilizers (Table 4.12 and Fig. 4.12). The average K availability in soil was 486.5, 504.0, 476.3 and 466.5 kg ha^{-1} at 30, 60, 90 DAS and at last harvest, respectively. The K availability was increased with period from sowing to 60 DAS and there after decreased up to harvesting stage in all the treatments. The decreased K availability in soil after 60 DAS may be due to higher uptake of K by plants at fruiting stage. The level of fertilizer had influenced the K availability in soil up to some extent.

Table 4.12. Periodical potassium availability in soil as influenced by different treatments

Tr. No.	Treatment	Potassium availability (kg ha^{-1})				
		Initial	**30 DAS**	**60 DAS**	**90 DAS**	**At last harvest**
T_1	DI with 100% RDF through fertigation as per schedule	472.5	490.4	512.0	483.2	469.3
T_2	DI with 80% RDF through fertigation as per schedule	472.5	488.6	507.7	478.5	466.0
T_3	DI with 60% RDF through fertigation as per schedule	472.5	482.4	505.5	473.4	464.4
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	472.5	489.7	509.9	480.2	471.3
T_5	DI with 100% RD of CF (soil)	472.5	493.6	508.4	478.8	474.5
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	472.5	489.7	511.3	482.7	470.1
T_7	DI with application of fertilizer as per soil test values	472.5	480.3	503.4	470.6	463.7
T_8	DI with no fertigation	472.5	470.6	469.4	460.5	453.0
T_9	SI with 100% RD of CF	472.5	492.8	508.3	479.5	466.2
	S.Em.$\pm$	-	1.00	0.67	0.97	1.07
	CD at 5%	-	3.00	2.00	2.90	3.20
	General mean	**472.5**	**486.5**	**504.0**	**476.3**	**466.5**

At 30 DAS, the significantly highest potassium availability is recorded in DI with 100 % RD of CF (T_5, 493.60 kg ha^{-1}); however, it is at par with T_9 (492.8 kg ha^{-1}). The lowest K availability was recorded in T_8 treatment (470.6 kg ha^{-1}). This might be due to the no fertigation to the soil in T_8. The higher availability of K in DI with 100% RD of CF (T_5) and SI with 100 % RD of CF (T_9) at 30 DAS may be due to the application of conventional fertilizer as basal dose at sowing.

At 60 DAS, the significantly highest potassium availability is recorded in DI with 100 % RDF through fertigation T_1 (512.0 kg ha^{-1}), however it is at par with T_6

(511.3 kg ha^{-1}) and T_4 (509.9 kg ha^{-1}). The lowest K availability was recorded in T_8 treatment (469.4 kg ha^{-1}). This might be due to the no fertigation applied in T_8.

The higher availability of K in drip irrigated treatments at 60 DAS was due to the application of water soluble fertilizers as per growth stages resumed in increased nutrient availability in root zone soil of okra. Similar trend of K availability was observed at 90 DAS. Almost similar results with were obtained by Varughese *et al*. (2014) in okra crop.

At last harvest, the significantly highest potassium availability is recorded in DI with 100 % RD of CF (T_5, 474.5 kg ha^{-1}), however it is at par with T_4 (471.3 kg ha^{-1}). The lowest K availability was recorded in T_8 treatment (453.0 kg ha^{-1}). The treatment T_5 where K was applied through soil resulted into more availability of potassium in soil at last harvest may be due to less K uptake as compared to drip fertigation treatments.

4.5.4 Nutrient use efficiency

The data on nutrient use efficiency as influenced by level of nutrients for different treatments are shown in Table 4.13.

The maximum nutrient use efficiency was obtained in treatment T_7 (DI with application of fertilizer as per soil test values) i.e. 67.5 kg yield kg^{-1} nutrient applied. The minimum nutrient use efficiency was obtained in treatment T_5 (DI with 100 % RD of CF) i.e. 40.2 kg yield kg^{-1} nutrient applied.

The maximum nitrogen use efficiency (NUE) was obtained in treatment T_7 (DI with application of fertilizer as per soil test values) i.e. 135.0 kg yield kg^{-1} nitrogen applied. The minimum NUE was obtained in treatment T_5 (DI with 100 % RD of CF) i.e. 80.5 kg yield kg^{-1} nitrogen applied.

The maximum phosphorus (PUE) and potassium (KUE) use efficiency was obtained in treatment T_7 (DI with application of fertilizer as per soil test values) i.e. 270.0 kg yield kg^{-1} nutrient applied. The minimum PUE and KUE was obtained in treatment T_5 (DI with 100 % RD of CF) i.e. 161.0 kg yield kg^{-1} nutrient applied. These results are in confirmation with research finding of Bharambe *et al*. (1997) they reported the higher NUE under drip fertigation over conventional practice in hybrid cotton.

Table 4.13 Nutrient use efficiency (Kg yield kg^{-1}nutrient) of okra as affected by different treatments

Tr. No.	Treatment	Nitrogen use efficiency (NUE))	Phosphorus use efficiency (PUE)	Potassium use efficiency (KUE)	Nutrient use efficiency
		(Kg yield kg^{-1}nutrient)			
T_1	DI with 100% RDF through fertigation as per schedule	134.0	268	268	67.0
T_2	DI with 80% RDF through fertigation as per schedule	128.5	257	257	64.2
T_3	DI with 60% RDF through fertigation as per schedule	119.0	238	238	59.5
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	107.0	214	214	53.5
T_5	DI with 100% RD of CF (soil)	80.5	161	161	40.2
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	113.0	226	226	56.5
T_7	DI with application of fertilizer as per soil test values	135.0	270	270	67.5
T_8	DI with no fertigation	0	0	0	0
T_9	SI with 100% RD of CF	94.5	189	189	47.2

4.6 Nutrient uptake by okra

The total uptake of nutrients was found to be influenced significantly due to different treatments. The total N, P and K uptake was increased with period from 30 DAS up to harvesting stage and maximum uptake of N, P and K by okra was observed at harvesting stage. The NPK uptake was improved significantly in drip fertigation treatments over DI with 100% RD of CF (T_5) and SI with 100% RD of CF (T_9).

4.6.1 Nitrogen uptake

The total N uptake as influenced by different treatments is presented in Table 4.14 and depicted in Fig.4.13. The average N uptake in plant was 8.54, 26.45, 56.32 and 74.09 kg ha^{-1} at 30, 60, 90 DAS and at last harvest, respectively. The periodical N uptake was increased with increase in age of the crop and maximum uptake was observed at harvesting stage.

Table 4.14. Periodical uptake of nitrogen in okra as influenced by different treatments

Tr. No.	Treatment	Nitrogen uptake (kg ha^{-1})					
		30 DAS	60 DAS	90 DAS	At last harvest		
					Plant	Fruit	Total
T_1	DI with 100% RDF through fertigation as per schedule	9.87	31.53	70.32	73.34	15.12	88.46
T_2	DI with 80% RDF through fertigation as per schedule	8.15	30.28	67.31	70.60	13.92	84.52
T_3	DI with 60% RDF through fertigation as per schedule	7.26	19.11	50.95	59.92	4.50	64.42
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	7.52	28.43	56.47	68.45	7.07	75.52
T_5	DI with 100% RD of CF (soil)	10.50	27.57	52.98	61.40	4.85	66.22
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	8.40	29.34	59.56	68.50	7.44	75.94
T_7	DI with application of fertilizer as per soil test values	10.30	33.00	70.32	79.12	16.74	92.85
T_8	DI with no fertigation	5.15	14.32	25.91	46.28	4.05	50.33
T_9	SI with 100% RD of CF	9.74	24.50	53.03	63.21	5.35	68.56
	S.Em.$\pm$	0.27	1.33	1.15	1.52	0.58	1.49
	CD at 5%	0.80	4.00	3.45	4.55	1.73	4.45
	General mean	**8.54**	**26.45**	**56.32**	**65.65**	**8.78**	**74.09**

At 30 DAS, significantly maximum N uptake of 10.50 kg ha^{-1} was found in treatment T_5 (DI with 100% RD of CF). However, it was at par with T_7 (10.30 kg ha^{-1}), T_1 (9.87 kg ha^{-1}) and T_9 (9.74 kg ha^{-1}). The lowest total N uptake was recorded in T_8 (5.15 kg ha^{-1}).

At 60 DAS, significantly maximum N uptake of 33.00 kg ha^{-1} was found in treatment T_7 (DI with fertigation as per soil test values). However, it was at par with T_1 (31.53 kg ha^{-1}), T_2 (30.28 kg ha^{-1}) and T_6 (29.34 kg ha^{-1}). The lowest total N uptake was recorded in T_8 (14.32 kg ha^{-1}).

At 90 DAS, significantly maximum N uptake of 73.21 kg ha^{-1} was found in treatment T_7 (DI with application of fertilizer as per soil test values). However, it was at par with T_1 (70.32 kg ha^{-1}). The lowest total N uptake was recorded in T_8 (25.91 kg ha^{-1}).

At last harvest, significantly maximum N uptake of 92.85 kg ha^{-1} (79.12 kg ha^{-1} by plant and 16.74 kg ha^{-1} by fruit) was found in treatment T_7 (DI with application of fertilizer as per soil test values). However, it was at par with T_1 (88.46 kg ha^{-1}). The lowest total N uptake was recorded in T_8 (50.33 kg ha^{-1}).

Water soluble fertilizers applied through drip recorded significant increase in uptake of nitrogen over conventional fertilizers applied through soil. This might be due to more availability of nutrients at different growth stages and maintenance of moisture at field capacity under drip irrigation as compared to surface irrigation with conventional fertilizers applied as basal dose (T_9). These results are in confirmation with research findings of Patil *et al.* (2009), Madhusoodana (2016) and Arunnaik *et al.* (2018) in okra crop.

4.6.2 Phosphorus uptake

The total P uptake as influenced by different treatments is presented in Table 4.15 and Fig. 4.14. The average P uptake in plant was 3.76, 8.01, 17.95 and 36.29 kg ha^{-1} at 30, 60, 90 DAS and at last harvest, respectively. The periodical P uptake was increased with increase in age of the crop and maximum uptake was observed at harvesting stage.

At 30 DAS, significantly maximum P uptake of 4.87 kg ha^{-1} was found in treatment T_5 (DI with 100 % RD of CF). However, it was at par with T_7 (4.26 kg ha^{-1}), T_1 (4.16 kg ha^{-1}) and T_9 (4.00 kg ha^{-1}). The lowest total P uptake was recorded in T_8 (2.10 kg ha^{-1}).

At 60 DAS, significantly maximum P uptake of 10.45 kg ha^{-1} was found in treatment T_7 (DI with application of fertilizer as per soil test values). However, it was at par with T_1 (9.68 kg ha^{-1}) and T_2 (9.27 kg ha^{-1}). The lowest total P uptake was recorded in T_8 (4.19 kg ha^{-1}). Similar trend of total P uptake was also observed at 90 DAS.

At last harvest, significantly maximum P uptake of 45.50 kg ha^{-1} (35.20 kg ha^{-1} by plant and 10.11 kg ha^{-1} by fruit) was found in treatment T_7 (DI with application of fertilizer as per soil test values). However, it was at par with T_1 (43.30 kg ha^{-1}) and T_2 (42.50 kg ha^{-1}). The lowest total P uptake was recorded in T_8 (16.13 kg ha^{-1}).

Table 4.15 Periodical uptake of phosphorus in okra as influenced by different treatments

Tr. No.	Treatment	Phosphorus uptake (kg ha^{-1})					
		30 DAS	60 DAS	90 DAS	At last harvest		
					Plant	Fruit	Total
T_1	DI with 100% RDF through fertigation as per schedule	4.16	9.68	21.35	33.98	9.52	43.30
T_2	DI with 80% RDF through fertigation as per schedule	3.66	9.27	20.24	33.23	9.27	42.50
T_3	DI with 60% RDF through fertigation as per schedule	3.40	6.11	14.43	26.95	6.46	33.42
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	3.56	8.26	18.51	28.93	7.82	36.75
T_5	DI with 100 % RD of CF (soil)	4.87	7.57	16.21	27.36	7.09	34.45
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	3.86	8.53	19.24	30.87	8.35	39.24
T_7	DI with application of fertilizer as per soil test values	4.26	10.45	22.91	35.20	10.11	45.50
T_8	DI with no fertigation	2.10	4.19	11.40	11.10	5.04	16.13
T_9	SI with 100% RD of CF	4.00	8.07	17.27	27.82	7.53	35.33
	S.Em.±	0.29	0.60	0.90	0.82	0.65	1.01
	CD at 5%	0.87	1.80	2.71	2.46	1.97	3.03
	General mean	**3.76**	**8.01**	**17.95**	**28.38**	**7.91**	**36.29**

The significantly maximum nutrient uptake in the fertigation treatments might be due to availability of sufficient moisture in root zone of the crop as per growth stages. Similar results were reported by Patil *et al.* (2009) and Imamsaheb *et al.* (2011).

4.6.3 Potassium uptake

The total K uptake as influenced by different treatments is presented in Table 4.16 and Fig. 4.14. The average K uptake in plant was 7.07, 34.38, 45.49 and 64.09 kg ha^{-1} at 30, 60, 90 DAS and at last harvest, respectively. The periodical K uptake was increased with increase in age of the crop and maximum uptake was observed at harvesting stage.

Table 4.16 Periodical uptake of potassium in okra as influenced by different treatments

Tr. No.	Treatment	Potassium (kg ha^{-1})					
		30 DAS	60 DAS	90 DAS	At last harvest		
					Plant	Fruit	Total
T_1	DI with 100% RDF through fertigation as per schedule	7.85	40.21	50.11	62.23	10.47	73.61
T_2	DI with 80% RDF through fertigation as per schedule	7.20	39.35	49.83	61.73	10.91	72.14
T_3	DI with 60% RDF through fertigation as per schedule	6.20	28.31	44.56	52.42	9.00	61.42
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	7.08	36.13	47.87	56.15	10.20	66.23
T_5	DI with 100% RD of CF (soil)	8.20	30.23	45.67	53.96	9.18	64.14
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	7.33	38.41	48.35	60.56	10.67	71.23
T_7	DI with application of fertilizer as per soil test values	8.05	43.35	51.87	64.04	11.38	74.52
T_8	DI with no fertigation	4.09	21.10	25.34	21.72	7.44	29.20
T_9	SI with 100% RD of CF	7.65	32.34	45.83	55.03	9.30	64.33
	S.Em.$\pm$	0.12	1.34	1.25	2.50	0.37	2.67
	CD at 5%	0.35	4.00	3.77	7.50	1.10	8.00
	General mean	**7.07**	**34.38**	**45.49**	**54.20**	**9.84**	**64.09**

At 30 DAS, significantly maximum K uptake of 8.20 kg ha^{-1} was found in treatment T_5 (DI with 100% RD of CF). However, it was at par with T_7 (8.05 kg ha^{-1}), T_1 (7.85 kg ha^{-1}) and T_9 (7.65 kg ha^{-1}). The lowest total K uptake was recorded in T_8 (5.09 kg ha^{-1}).

At 60 DAS, significantly maximum K uptake of 43.35 kg ha^{-1} was found in treatment T_7 (DI with application of fertilizer as per soil test values); however, it was at par with T_1 (40.21 kg ha^{-1}), T_2 (39.35 kg ha^{-1}). The lowest total P uptake was recorded in T_8 (21.10 kg ha^{-1}). Similar trend of total K uptake was also observed at 90 DAS.

At last harvest, significantly maximum K uptake of 74.52 kg ha^{-1} (64.04 kg ha^{-1} by plant and 10.47 kg ha $^{-1}$ by fruit) was found in treatment T_7 (DI with application of fertilizer as per soil test values). However, it was at par with T_1 (73.61 kg ha^{-1}), T_2 (72.14 kg ha^{-1}) and T_6 (71.23 kg ha^{-1}). The lowest total K uptake was recorded in T_8 (29.20 kg ha^{-1}). Similar trend of total K uptake was also observed at 90 DAS.

The significantly maximum uptake in the drip fertigation treatments as compared to SI with 100 % RD of CF (T_9) might be due to availability of sufficient moisture and nutrients in root zone of the crop as per growth stage. These results are in confirmation with the research findings of Patil *et al.* (2009) in cotton crop.

4.7 Effect of fertigation on P fractions

The P fractions in soil are greatly influenced by the sources and the level of nutrients. The data regarding the P fractions for different growth stages is presented in tables 4.17 to 4.20. Amongst the P fractions the highest values has been observed for Ca-P followed by Red-P, Al-P, Fe-P, Sal-P and Occl- P.

The conversion of soluble P into various forms of P varying in their solubility depends on the soil reaction, content of sesquioxides, free $CaCO_3$, Al_2O_3 and organic carbon. Similar results were reported by Kulkarni (1994).He reported the high content of Ca-P and Red-P in Sawargaon and Dholwad soil series from inceptisol order similarly Gajbhiye (2001) reported that the major part of total P was contributed by inorganic P.

At 30 DAS, P fractions were greater for DI with 100 % of CF (T_5) i.e. 20.23, 38.19, 32.36, 400.41, 89.78, 19.08, 224.18 and 824.23 mg kg^{-1} for Sal-P, Al-P, Fe-P, Ca-P, Red-P, Occl-P, organic-P and total-P respectively followed by T_4 while it was lower for no fertilizer treatments. This is due to the readily available P fractions through initial basal application of fertilizers (Table 4.14).

At 60 DAS, P fractions were highest for T_7 i.e. 26.61, 44.14, 35.53, 433.44, 89.20, 22.68, 247.40 and 855.29 mg kg^{-1} for Sal-P, Al-P, Fe-P, Ca-P, Red-P, Occl-P, organic-P and total-P respectively. Similar trend was followed at 90 DAS. Similar results were reported by Sarawgi *et al.* (2012) and Neha Ranjan (2018) in tomato.

At last harvest, the maximum P fractions were observed in T_5 i.e. 15.36, 29.45, 23.53, 349.36, 75.57, 12.40, 289.08 and 794.75 mg kg^{-1} for Sal-P, Al-P, Fe-P, Ca-P, Red-P, Occl-P, organic-P and total-P followed by T_4. The highest values for available P fractions may be due to less uptake of P by okra as compare to other treatments.

Table 4.17 P fractions at 30 DAS

Tr. No.	Treatment	Sal-P	Al-P	Fe-P	Ca-P	Red-P	Occl-P	Organic P	Total P
		mg kg^{-1}							
T_1	DI with 100% RDF through fertigation as per schedule	17.29	36.12	28.27	384.26	82.28	16.79	220.16	785.17
T_2	DI with 80% RDF through fertigation as per schedule	16.22	35.00	27.31	368.39	81.82	15.59	239.10	783.43
T_3	DI with 60% RDF through fertigation as per schedule	9.31	27.20	21.18	353.30	62.51	10.74	280.96	765.20
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	18.29	36.19	29.19	389.34	83.61	18.62	217.05	792.29
T_5	DI with 100% RD of CF (soil)	20.23	38.19	32.36	400.41	89.78	19.08	224.18	824.23
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	15.08	28.48	25.28	359.32	80.38	15.77	252.16	776.47
T_7	DI with application of fertilizer as per soil test values	15.61	29.15	26.20	364.58	81.17	16.15	247.40	780.26
T_8	DI with no fertigation	8.04	21.26	20.25	342.12	60.35	9.24	298.98	760.24
T_9	SI with 100% RD of CF	19.04	37.20	30.13	392.23	85.18	18.22	230.11	812.11
	S.Em.±	0.60	0.51	0.50	0.60	0.38	0.54	0.52	0.58
	CD at 5%	1.80	1.54	1.52	1.81	1.16	1.64	1.72	1.74
	General mean	**15.46**	**32.09**	**26.69**	**372.66**	**78.56**	**15.58**	**245.57**	**786.60**

Table 4.18 P fractions at 60 DAS

Tr. No.	Treatment	Sal-P	Al-P	Fe-P	Ca-P	Red-P	Occl-P	Organic P	Total P
		mg kg^{-1}							
T_1	DI with 100% RDF through fertigation as per schedule	25.24	42.68	34.42	428.34	87.36	20.02	212.12	850.14
T_2	DI with 80% RDF through fertigation as per schedule	24.40	41.42	33.21	410.12	81.05	21.52	220.36	828.36
T_3	DI with 60% RDF through fertigation as per schedule	22.43	35.47	29.47	392.61	74.11	18.36	238.42	810.87
T_4	DI with 100% RD of CF (N and K –drip and P- soil)	23.72	40.20	30.84	405.23	80.29	20.22	225.76	826.26
T_5	DI with 100% RD of CF (soil)	23.18	38.48	30.27	395.13	75.00	19.46	243.68	825.20
T_6	DI with 100% RDF through fertigation in 7 equal weekly splits	24.61	41.43	33.44	425.37	84.20	18.55	213.18	843.30
T_7	DI with application of fertilizer as per soil test values	26.61	44.14	35.53	433.43	89.20	22.68	203.8	855.39
T_8	DI with no fertigation	14.37	30.49	23.76	376.26	66.42	15.08	276.22	802.60
T_9	SI with 100% RD of CF	20.11	32.42	24.49	382.54	69.28	16.01	261.56	806.41
	S.Em.$\pm$	0.61	0.59	0.60	0.60	3.95	0.61	0.54	0.49
	CD at 5%	1.83	1.77	1.82	1.82	11.85	1.84	1.56	1.48
	General mean	**22.74**	**38.53**	**30.60**	**405.45**	**78.55**	**19.10**	**232.79**	**827.61**

Table 4.19 P fractions at 90 DAS

Tr. No.	Treatment	Sal-P	Al-P	Fe-P	Ca-P	Red-P	Occl-P	Organic P	Total P
		mg kg^{-1}							
T_1	DI with 100 % RDF through fertigation as per schedule	22.12	37.62	33.53	389.12	87.11	19.81	230.89	820.20
T_2	DI with 80 % RDF through fertigation as per schedule	20.72	36.11	32.42	387.22	86.27	18.72	239.19	815.44
T_3	DI with 60 % RDF through fertigation as per schedule	19.06	32.45	29.47	363.07	83.43	16.77	234.98	779.23
T_4	DI with 100 % RD of CF (N and K –drip and P- soil)	20.23	35.38	30.84	381.27	85.48	17.82	244.22	815.24
T_5	DI with 100 % RD of CF (soil)	19.64	34.45	30.27	368.02	84.27	17.07	233.37	787.09
T_6	DI with 100 % RDF through fertigation in 7 equal weekly splits	21.74	36.39	32.21	382.18	86.36	18.62	233.63	816.44
T_7	DI with application of fertilizer as per soil test values	22.30	38.44	34.22	394.46	88.45	20.34	227.29	825.46
T_8	DI with no fertigation	11.56	25.11	23.76	346.35	66.32	10.34	279.7	763.14
T_9	SI with 100 % RD of CF	16.21	29.47	24.49	355.16	76.09	11.59	257.28	770.29
	S.Em.±	0.51	0.01	0.51	0.50	0.62	0.60	0.53	0.59
	CD at 5%	1.53	0.05	1.53	1.52	1.86	1.82	1.47	1.77
	General mean	**19.29**	**33.94**	**30.13**	**374.09**	**82.64**	**16.79**	**242.28**	**799.17**

Table 4.20 P fractions at last harvest of okra

Tr. No.	Treatment	Sal-P	Al-P	Fe-P	Ca-P	Red-P	Occl-P	Organic P	Total P
		mg kg^{-1}							
T_1	DI with 100 % RDF through fertigation as per schedule	13.35	26.22	20.71	338.60	69.10	10.09	290.25	768.32
T_2	DI with 80 % RDF through fertigation as per schedule	12.71	25.85	20.48	346.28	73.28	11.86	282.74	773.20
T_3	DI with 60 % RDF through fertigation as per schedule	7.67	23.57	17.69	335.68	65.42	6.22	291	748.25
T_4	DI with 100 % RD of CF (N and K –drip and P- soil)	13.41	26.30	21.36	342.26	71.57	10.04	290.69	775.63
T_5	DI with 100 % RD of CF (soil)	15.36	29.45	23.53	349.36	75.57	12.40	289.08	794.75
T_6	DI with 100 % RDF through fertigation in 7 equal weekly splits	9.15	24.17	18.41	340.56	68.33	8.59	290.96	760.17
T_7	DI with application of fertilizer as per soil test values	11.75	24.85	19.52	344.59	72.28	11.01	279.5	763.50
T_8	DI with no fertigation	6.24	20.59	15.09	330.49	50.56	4.38	316.94	744.29
T_9	SI with 100 % RD of CF	14.50	28.29	21.22	348.27	72.43	11.91	287.49	784.11
	S.Em.±	0.58	0.60	0.58	0.01	0.19	0.59	0.53	0.02
	CD at 5%	1.74	1.79	1.76	0.05	0.57	1.78	0.63	0.06
	General mean	**11.57**	**25.48**	**19.78**	**341.79**	**68.73**	**9.61**	**290.96**	**768.02**

4.8 Correlation of P fractions with different forms of P, nutrient uptake, nutrient availability and yield

All the P fractions were positively correlated with different forms of P, nutrient uptake by okra, nutrient availability in soil and yield of okra.

These data are presented in Table 4.21. It can be observed that total-P had high degree of significance and positive relationship with all the inorganic P fractions. Similar results were also observed by Bhardwaj *et al.* (1994).

Significant relationship among the various forms of P indicates that there is an existence of dynamic equilibrium among the different P fractions. Prasad *et al.* (1986) reported that all the P forms were related to each other. Kothandaraman and Krishnamoorthy (1979) observed a close relationship between total-P and other forms of P indicating the existence of equilibrium between Total-P and P fractions.

The N uptake is positive and significantly correlated with all the P fractions *viz.,* Sal-P=0.896^{**}, Al-P=0.927^{*}, Fe- P=0.880^{*}, Ca-P=0.717^{**}, Red-P=0.651^{*}, Occl-P=0.762^{*} and Total-P=0.915^{*}. Similar correlation is also observed for the P and K uptake by the plant. Rane and Patel (1989) concluded that there was positive and significant correlation between all the forms of P and NPK uptake.

The data in Table 4.18 with respect to correlation between forms of P and yield; indicated the significant and positive relationship with Sal-P=0.855^{**}, Al-P=0.897^{*}, Fe-P=0.909^{**}, Ca-P=0.957^{*}, Red-P=0.922^{*}, Occl-P=0.929^{*} and Total-P=0.974^{*}. Rokima and Prasad (1991) observed that all the P fractions were found to be correlated with yields (r=0.77^{*} to 0.99^{*}) in soybean.

The N availability has significant and positive correlation with all the P fractions (Table 4.19) i.e. Sal-P=0.931^{**}, Al-P=0.900^{**}, Fe-P=0.874^{**}, Ca-P=0.827^{*}, Red-P=0.965^{*}, Occl- P=0.955^{**} and Total-P=0.902^{**}.

The P availability is also positively correlated with P fractions except for Ca-P (0.662) as P is tightly bound to calcium. The K availability is positive and significant with all P fractions except Al-P, Ca-P and Total-P. The positive and significant relation between P fractions and NPK availability was also confirmed by Rane and Patel (1989) and More and Agal (1994).

Table 4.21 Correlation of P fractions with different forms of P, nutrient uptake, nutrient availability and yield at last harvest of okra

	P fraction							Nutrient uptake			Nutrient availability			Yield
	Sal-P	Al-P	Fe-P	Ca-P	Red-P	Occl-P	Total-P	N	P	K	N	P	K	
Sal-P	1													
Al-P	0.952**	1												
Fe-P	0.966**	0.974**	1											
Ca-P	0.865*	0.889	0.869*	1										
Red-P	0.842*	0.869	0.893*	0.904	1									
Occl-P	0.938*	0.897*	0.909**	0.957	0.922**	1								
Total-P	0.951**	0.965**	0.955**	0.900*	0.800	0.898*	1							
N uptake	0.896**	0.927*	0.880*	0.717**	0.651*	0.762*	0.915*	1						
P uptake	0.958**	0.902*	0.947**	0.777**	0.961*	0.830*	0.977*	0.868**	1					
K uptake	0.907**	0.915*	0.754	0.805**	0.800*	0.764*	0.965*	0.955**	0.900**	1				
Available N	0.631**	0.900**	0.874**	0.827*	0.965**	0.955**	0.902**	0.786*	0.898**	0.922**	1			
Available P	0.541*	0.840*	0.920**	0.662	0.957*	0.947*	0.905*	0.800*	0.892*	0.531*	0.423**	1		
Available K	0.444*	0.601	0.595**	0.646	0.965*	0.955	0.900	0.806	0.885*	0.897*	0.909*	0.957**	1	
Yield	0.855**	0.897*	0.909**	0.957*	0.922*	0.929*	0.974*	0.838**	0.965**	0.955	0.900*	0.806*	0.898*	1

* = Significant at 0.05 level ** = Significant at 0.01 level

4.9 Economics

The data regarding the seasonal cost, net seasonal income, B:C ratio and net extra income over control of okra as influenced by different fertigation treatments are presented in Table 4.22 and Appendix I to III.

4.9.1 Seasonal cost

The cost of cultivation of drip irrigation treatments observed higher than surface irrigated treatments due to higher cost of installation of drip systems (Table 4.22 and Appendix III). Cost of fertilizer was different as full recommended dose of fertilizers was not applied in all the treatments. The highest cost of cultivation was observed in treatment T_1 (Rs. 95,487) followed by T_6 (Rs. 95,414) and lowest cost of cultivation was observed in T_8 (Rs. 78,581) followed by T_9 (Rs. 82,175) as the cost of water soluble fertilizers was about double to that of conventional fertilizers.

4.9.2 Net seasonal income

The data regarding the net seasonal income indicated maximum values per ha was recorded in treatment T_7 (Rs. 2,98,055) due to higher yield followed by treatment T_1 (Rs. 2,65,713).Treatment T_8 gave lowest yield of fruit hence the net seasonal income was also lowest as Rs. 44,419.

All fertigation treatments gave more net seasonal income than conventional fertilizer application treatments. These results are in close conformity with the results of Pawar *et al.* (2013).

4.9.3 B:C ratio

The treatment is said to be profitable when the B:C ratio is more than 1 and if it is less than 1, then treatment shows more expenditure than income i.e. not profitable and if its value is 1 then there is no loss or profit.

All treatments recorded B:C ratio between 1.57 to 4.21. Maximum values of B:C ratio was recorded in treatment T_7 (DI with application of fertilizer as per soil test values) i.e. 4.21 followed by T_1 (DI with 100% RDF through fertigation) i.e. 3.78. The lowest B:C ratio was observed in T_8 (1.57). These results are in close conformity with the results of Pawar *et al.* (2013).

Table 4.22. Economics of okra as influenced by different treatments

Treatment	Seasonal cost (Rs ha^{-1})	Net seasonal income (Rs ha^{-1})	B:C ratio	Net extra income over control (T_5) (Rs)	Water productivity (Rs. ha^{-1} mm^{-1})
T_1	95487	265713	3.78	67735	430.41
T_2	92413	246587	3.67	48609	399.43
T_3	89338	187862	3.10	-10116	304.30
T_4	90382	246618	3.73	48640	399.48
T_5	86022	197978	3.30	0	320.69
T_6	95414	253586	3.66	55608	410.77
T_7	92945	298055	4.21	100077	482.80
T_8	78581	44419	1.57	-153559	71.95
T_9	82175	229825	3.80	31847	251.20

4.4.4 Net extra income over control

The net extra income over control (T_5) was highest in treatment T_7 (Rs. 1,00,077) followed by T_1 (Rs. 67,735) All fertigation treatments gave more income than conventional fertilizer application treatment.

4.9.5 Water productivity

The data regarding water productivity as influenced by different fertigation treatments are presented in Table 4.22. The maximum value of water productivity was recorded in T_7 (DI with application of fertilizer as per soil test values) i.e. Rs. 482.80 ha^{-1} mm water used followed by T_1 (Rs. 430.41 ha^{-1} mm water used). The minimum water productivity was recorded for T_8 i.e. Rs. 71.05 ha^{-1} mm water used.

5. SUMMARY AND CONCLUSIONS

A field experiment on "Effect of water soluble fertilizers through drip fertigation on yield of *summer* okra, nutrient uptake, nutrient availability and P fractions in Inceptisol" was conducted during 2018-19 at the experimental farm of Interfaculty Department of Irrigation Water Management, PGI, Mahatma Phule Krishi Vidyapeeth, Rahuri, District Ahmednagar, Maharashtra, India.

The experiment was laid out in Randomized Block Design with three replications and nine treatments. The soil of the experimental site was uniform and leveled. The soil was well Silty clay in texture with 70 cm depth, low in available nitrogen (165.0 kg ha^{-1}), medium in available phosphorus (18.2 kg ha^{-1}) and very high in available potassium (472.5 kg ha^{-1}). The soil was slightly alkaline in reaction with pH as 8.15 and EC values of 0.39 dSm^{-1}. The values of field capacity, permanent wilting point, bulk density, infiltration rate and available soil moisture content were 39.15 per cent, 17.14 per cent, 1.22 Mg m^{-3}, 4.14 cm hr^{-1} and 22 per cent, respectively. Sowing of okra was done on February 25, 2019 at 0.30 x 0.15 m (4 lines per BBF of 1.20 m top and 1.50 m bottom) spacing. The irrigations were provided as per requirement. The cultural operations and plant protection measures were carried out timely.

The observations on periodical growth and yield contributing characters were recorded. The plant and soil samples were collected periodically to estimate the nutrient availability in soil and uptake by plants. Chemical analysis for estimation of N, P and K in soil and plant was carried out. Some of the findings emerged are summarized below.

5.1 Summary

5.1.1 Growth parameters

5.1.1.1 Plant height

Drip irrigation with application of fertilizer as per soil test values (T_7) recorded significantly maximum plant height (46.17, 87.38 and 111.86 cm) at 60, 90 DAS and at last harvest. However, it was at par with treatment T_1, T_6 and T_2. The highest plant height in T_7 might be due to effect of fertilization at proper growth stages and use of the water soluble fertilizers according to the soil test values rather than conventional fertilizers.

5.1.1.2 Number of leaves

The maximum number of leaves of (24.50 and 34.00) were recorded for T_7 (Drip irrigation with application of fertilizer as per soil test values) at 60 and 90 DAS, respectively. However, it was at par with treatment T_1, T_2 and T_6. The increase in number of leaves due to different treatments may be attributed to the fact that judicious use of appropriate fertilization rendered to the soil helped in supply of balanced nutrients.

5.1.1.3 Length of fruits

The drip irrigation with application of fertilizer as per soil test values (T_7) recorded significantly maximum length of fruits (10.53, 12.16 and 11.06 cm) at 60, 90 DAS and at last harvest, respectively. However, it was at par with treatment T_1, T_2 and T_6 at 60 and 90 DAS. The treatment T_8 (7.23, 7.55 and 6.39 cm) recorded minimum length of fruit at all stages of crop growth. This may be due to lack of fertilization rendered to the soil.

5.1.1.4 Chlorophyll Content

The drip irrigation with application of fertilizer as per soil test values (T_7) recorded significantly maximum chlorophyll content (46.05, 42.12 and 38.46 $\mu mol/m^{2)}$ at 60, 90 DAS and at harvest, respectively. However, it was at par with treatment T_1 and T_2 at 60, 90 DAS and at harvest.

5.1.1.5 Days required for 50 per cent flowering (days)

The data revealed that the treatment T_7 i.e. Drip irrigation with application of fertilizer as per soil test values (42.03 days) showed early 50 per cent flowering, followed by T_1 (42.31 days) and T_2 (43.01 days) and the treatment T_8 i.e. DI with no fertigation (45.02 days) recorded late 50 per cent flowering.

5.1.1.6 Days required for fruit initiation (days)

The data revealed that the treatment T_7 i.e. Drip irrigation with application of fertilizer as per soil test values (47.27 days) showed early fruit initiation, followed by T_1 (48.12 days) and T_2 (48.23 days) and the treatment T_8 i.e. DI with no fertigation (52.26 days) recorded late fruit initiation.

5.1.1.7 Days required for fruit maturity (days)

The data revealed that the treatment T_7 i.e. Drip irrigation with application of fertilizer as per soil test values (55.77 days) showed early fruit maturity, followed by

T_1 (57.05 days) and T_2 (57.21 days) and the treatment T_8 i.e. DI with no fertigation recorded late fruit maturity as 61.28 days.

5.1.1.8 Dry matter content

At 60 DAS, DI with application of fertilizer as per soil test values (T_7) recorded significantly more dry matter accumulation (9.43 g plant^{-1}). However, it was at par with T_1, T_2, T_6 and T_4. Treatment T_8 recorded minimum dry matter accumulation of 4.08 g plant^{-1}. Similar trend of dry matter accumulation was observed at 90 DAS and at last harvest. There was maximum accumulation of dry matter plant^{-1} in drip fertigation with water soluble fertilizer treatments at 60, 90 DAS, at harvest as compared to surface irrigation (SI) with 100% RD of fertigation through CF (T_9). This may be due to the profused vegetative growth on account of optimum moisture and nutrient supply, in the rhizosphere during the okra crop at growth period.

5.1.2 Micrometeorological observations

5.1.2.1 Photosynthetic rate

The highest photosynthetic rate is observed in T_7 (36.47, 40.25 and 34.27 µmol m^{-2} sec^{-1}) while it is lowest in T_8 (27.60, 31.50 and 25.62 µmol m^{-2} sec^{-1}) at 30, 60 and 90 DAS, respectively.

5.1.2.2 Stomatal conductance

Stomatal conductance is highest in T_7 at every stages i.e. 1.35, 1.93 and 1.07 mmol m^{-2} s^{-1} at 30, 60 and 90 DAS, respectively and it was at par with T_1 and lowest stomatal conductance was recorded in T_8 i.e. 0.43, 0.65 and 0.32 µmol m^{-2} s^{-1} at 30, 60 and 90 DAS, respectively.

5.1.2.3 Stomatal resistance

The stomatal resistance is highest recorded in T_9 (1.45, 1.71 and 1.32 µmol m^{-2} s^{-1}) and lowest value was recorded in T_7 (0.57, 0.84 and 0.41 µmol m^{-2} s^{-1}) at 30, 60 and 90 DAS. The lowest stomatal resistance in T_7 was due to the maximum nutrient availability to the crop which resulted in the better absorption of PAR for biomass production.

5.1.2.4 Leaf temperature

The leaf temperature was influenced significantly due to fertigation treatments at 30, 60 and 90 DAS. The data are presented in Table 4.7. Significantly lower leaf temperature was recorded in T_7 i.e. 28.36°C.

5.1.2.5 Transpirational rate

The highest transpiration rate is observed for T_7 [DI with application of fertilizer as per soil test values] i.e. 15.45, 15.81, and 14.29 µmol CO_2 $m^{-2}s^{-1}$ at 30, 60 and 90 DAS respectively. The lowest values were recorded for T_8 (DI with no fertigation) i.e. 6.17, 7.29 and 5.30 µmol CO_2 $m^{-2}s^{-1}$ at 30, 60 and 90 DAS respectively.

5.1.3 Yield and yield contributing characters

5.1.3.1 Number of fruits

The data regarding the number of fruits plant^{-1} revealed that the significantly higher number of fruits plant^{-1} was recorded treatment T_7 i.e. Drip irrigation with application of fertilizer as per soil test values (20.81), however, it was at par with T_1 (20.32), T_2 (19.60) and T_6 (19.22). Treatment T_8 (DI with no fertigation) recorded the lowest number of fruits plant^{-1} i.e. 8.30. The drip fertigation treatments show significantly maximum number of fruits per plant. This might be due to maximum number of branches and leaf produced in these treatments

5.1.3.2 Weight of fruits (g)

The weight of fruits plant^{-1} was recorded significantly highest for T_7 (182.24 g), however, it was at par with T_1 (181.80), T_2 (180.30 g) and T_6 (176.00). Treatment T_8 (DI with no fertigation) recorded the lowest weight of fruits plant^{-1} i.e. 87.72 g.

5.1.3.3 Yields

The data regarding the yield of okra in tones ha^{-1} are presented in Table 4.7, it was observed that drip irrigation with application of fertilizer as per soil test values T_7 (19.55 t ha^{-1}) recorded significantly maximum yield over DI with 100% RD of CF T_5 (14.20 t ha^{-1}). However, it was at par with T_1 (18.06 t ha^{-1}), T_2 (16.95 t ha^{-1}) and T_6 (17.45). The per cent increase in yield over Drip irrigation with conventional fertilizer (T_5) is higher for T_7 (37.67%) followed by T_1 (27.18 %).

5.1.4 Water requirement

The average water requirement of okra under different irrigation methods was ranged from 617.3- 914.9 mm. The drip method of irrigation resulted into lowest water use (617.3 mm) as compared to surface method of irrigation (934.9 mm) and thus resulted into 42.2 per cent water saving in drip irrigation system.

5.1.5 Water use efficiency

The maximum values of WUE was obtained in drip irrigation with application of fertilizer as per soil test values T_7 (31.67 kg ha^{-1} mm) followed by T_1 (29.26 kg ha^{-1} mm) and T_6 (28.27 kg ha^{-1}mm).

5.1.6 Nutrient availability in soil

The N, P and K in soil was significantly influenced due to fertigation treatments as the fertilizers were applied in 12 weekly splits scheduled according to growth stages of okra crop. The maximum availability was observed at 60 DAS. The treatment T_7 recorded maximum availability of N and P as 193.63 and 38.55 kg ha^{-1}, whereas T_1 recorded maximum K availability of 512 kg ha^{-1}, respectively at 60 DAS. The lowest N, P and K availability was observed in T_8 i.e. no fertigation treatment as 163.7, 15.7 and 469.4 kg ha^{-1} at 60 DAS.

5.1.7 Nutrient use efficiency

The maximum nutrient use efficiency was obtained in treatment T_7 (DI with application of fertilizer as per soil test values) i.e. 67.5 kg yield kg^{-1} nutrient applied. The minimum nutrient use efficiency was obtained in treatment T_5 (DI with 100% RD of CF) i.e. 40.2 kg yield kg^{-1} nutrient applied.

5.1.8 Nutrient uptake

The drip irrigation with application of fertilizer as per soil test values was recorded significantly maximum uptake of nutrients. The significantly maximum uptake of N, P and K was found in treatment T_7 (95.86, 45.50, 74.52 kg ha^{-1}, respectively) at last harvest. The higher NPK uptake may be due to application of water soluble fertilizers in more number of splits apportioned as per crop growth stages which helped to increase uptake. In treatment T_8, lowest value of N, P and K uptake (61.33, 16.13, 29.20 kg ha^{-1}, respectively) was observed at last harvest of okra crop.

5.1.9 P fractions in soil

DI with application of fertilizer as per soil test values i.e. (T_7) recorded significantly maximum P fractions at 60 and 90 DAS and it was at par with T_1 for all the P fractions while T_5 recorded significantly maximum P fractions at 30 DAS and at last harvest. The P fractions were significant and positively correlated with different forms of P, nutrient uptake by okra, nutrient availability in soil and yield of okra at last harvest.

5.2 Economics of okra

The cost of cultivation of drip irrigation treatments observed higher than surface irrigated treatments due to higher cost of installation of drip systems (Table 21. and Appendix III). Cost of fertilizer was different as full recommended dose of fertilizers was not applied in all the treatments. The highest cost of cultivation was observed in treatment T_1 (Rs. 95,487) followed by T_6 (Rs. 95,414) and lowest cost of cultivation was observed in T_8 (Rs.78,581) followed by T_9 (Rs. 82,175) as the cost of water soluble fertilizers was about double to that of conventional fertilizers.

5.2.1 Conclusion

Looking to the results of the study on "Effect of water soluble fertilizers through drip fertigation on yield of summer okra, nutrient uptake, nutrient availability and P fractions in Inceptisol" the following conclusions were drawn:

1. All the growth and yield contributing characters of okra was found maximum in T_7; however, it was at par with T_1 and T_2 in many characters.
2. Significantly highest yield of okra was obtained in treatment T_7 where WSF were applied as per soil test values in 12 weekly splits as per crop growth stages with drip irrigation system. However it was at par with treatment T_1, T_2 and T_6.
3. The nutrient availability and uptake was improved significantly in treatment T_7 and T_1 with fertigation of water soluble fertilizers over DI with 100% RD of CF (soil) (T_5) and surface method of irrigation and conventional fertilization (T_9).
4. DI with application of fertilizer as per soil test values i.e. (T_7) recorded significantly maximum P fractions while T_5 recorded significantly maximum P fractions at 30 DAS and at last harvest. The P fractions were significant and positive correlated with different forms of P, nutrient uptake by okra, nutrient availability in soil and yield of okra at last harvest.

5. The treatment T_7 (DI with application of fertilizer as per soil test values) recorded significantly higher net seasonal income (Rs. 2,98,055), B:C ratio (4.21), net extra income over control (Rs. 1,00,077), and water productivity of water (Rs. 482.80 ha^{-1} mm) as compared to surface irrigation.

Thus, it is concluded that the drip irrigation with application of fertilizer as per soil test values (125:50:25 N, P_2O_5 and K_2O kg ha^{-1}) found best in terms of growth contributing characters, yield, water use and economical returns from okra and hence may be recommended for cultivation in silty clay soils of western Maharashtra.

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7. APPENDICES

Appendix-I : Cost of cultivation of okra

Particulars	T1		T2		T3		T4		T5		T6		T7		T8		T9	
	Qty	Cost	Qty	Cost	Qty	Cost	Qty	Cost	Qty	Cost	Qty	Cost	Qty	Cost	Qty	Cost	Qty	Cost
Labour charges @ 205/ day	145	29725	145	29725	145	29725	145	29725	145	29725	145	29725	145	29725	138	28290	198	40590
Water charges @ 71.40 1000m^3	5.2	371.2	5.2	371.2	5.2	371.2	5.2	371.2	5.2	371.2	5.2	371.2	5.2	371.2	5.2	371.2	8.1	579.7
Ploughing 4000/ha	1	4000	1	4000	1	4000	1	4000	1	4000	1	4000	1	4000	1	4000	1	4000
Harrowing @ 2000	1	2000	1	2000	1	2000	1	2000	1	2000	1	2000	1	2000	1	2000	1	2000
seed rate@ 16/kg	18	9000	18	9000	18	9000	18	9000	18	9000	18	9000	18	9000	18	9000	18	9000
Insecticide/pesticide		5100		5100		5100		5100		5100		5100		5100		5100		5100
Fertlizer																		
Urea @ 6 /kg	175	1050	140	840	105	630	217	1302	217	1302	175	1050	230	1380	0	0	217	1302
17:44 @ 65/kg	114	7410	91	5915	68	4420	0	0	0	0	113	7345	114	7410	0	0	0	0
SOP @ 52/kg	100	5200	80	4160	60	3120	0	0	0	0	100	5200	50	2600	0	0	0	0
SSP @ 8/kg			0		0		312	2496	312	2496	0		0				312	2496
MOP @17/kg			0	0	0	0	83	5304	83	1411	0		0	0			83	1411
Electricity charges		2000		2000		2000		2000		2000		2000		2000		2000		2000
A. Working capital (3 to 11)		65856.2		63111		60366		61298		57405		65791.2		63586		50761.2		68478.8
B. Interest on working capital @ 12 % p. a.		7902.7		7573		7244		7356		6889		7894.9		7630		6091.3		8217.4
C. Rental value of land		3000		3000		3000		3000		3000		3000		3000		3000		3000
OperationalCost		**76759**		**73685**		**70610**		**71654**		**67294**		**76686.2**		**74217**		**59852.6**		**79696.2**

Appendix –II : Economic of okra crop

Sr. No.	Items	T1	T2	T3	T4	T5	T6	T7	T8	T9
1	Fix Cost (Rs. ha^{-1})	18727.8	18727.84	18727.84	18727.84	18727.84	18727.84	18727.84	18727.84	2479
2	Operational Cost (Rs.)	76759	73685	70610	71654	67294	76686	74217	59853	79696
3	Seasonal Cost (Rs. ha^{-1})	95487	92413	89338	90382	86022	95414	92945	78581	82175
4	Water used (mm)	617.35	617.35	617.35	617.35	617.35	617.35	617.35	617.35	914.9
5	Yield of okra (t ha^{-1})	18.06	16.95	13.86	16.85	14.2	17.45	19.55	6.15	15.6
6	Selling price (Rs. kg ha^{-1})	20000	20000	20000	20000	20000	20000	20000	20000	20000
7	Income from produce (Rs. ha^{-1})	361200	339000	277200	337000	284000	349000	391000	123000	312000
8	Net seasonal income (Rs. ha^{-1})	265713	246587	187862	246618	197978	253586	298055	44419	229825
9	Net profit/mm water use (Rs.)	430.41	399.43	304.30	399.48	320.69	410.77	482.80	71.95	251.20
10	B:C ratio	3.78	3.67	3.10	3.73	3.30	3.66	4.21	1.57	3.80
11	Net extra income over control (T_5) Rs.	67735	48609	10116-	48640	0	55608	100077	153559-	31847
12	WUE (kg ha^{-1} mm)	29.25	27.46	22.45	27.29	23.00	28.27	31.67	9.96	17.05

Appendix-III : Economics of drip and surface irrigation for okra crop

Sr. No.	Item	Qty	Rate per unit	Cost (Rs.)	Life (years)	Junk value	Depreciation=(OC-JV)/L	Interest @ 12 per cent pa (Rs)	Repaire and maintenance @ 2 per cent pa
I.	**Drip systems**								
1	Centrifugal pump set (5HP) and accessories	1	8000	8000	20	800	360	960	160
2	Sand Filter	1	3000	3000	10	300	270	360	60
3	Bypass	1	1000	1000	10	100	90	120	20
4	PVP pipe, 90 mm (main-50 m ha^{-1}) @ 90 Rs. m^{-1}	50	90	4500	6	450	675	540	90
5	PVP pipe, 63 mm (submain-75m ha^{-1}) @ 48 Rs. m^{-1}	200	48	9600	6	960	1440	1152	192
6	LDPE lateral 16 mm (8300 m) @ 10.95Rs. m^{-1}	8300	10.95	90885	6	9088.5	13632.75	10906.2	1817.7
	GTO for LDPE lateral 16 mm @ 3.5 Rs/unit (for 166 laterals)	166	3.5	581	6	58.1	87.15	69.72	11.62
7	LDPE end caps @ 2.5 Rs. $unit^{-1}$ (for 166 laterals)	166	2.5	415	6	41.5	62.25	49.8	8.3
8	PVC fittings	1.0	200.0	2000.0	6.0	200.0	300.0	240.0	40.0
9	Valves	1.0	443.0	443.0	6.0	44.3	66.5	53.2	8.9
10	Total fixed cost			120424.0		12042.4	16983.6	14450.9	2408.5
11	Installation @ 3 per cent of total cost	3612.72							
	Total annual cost	37455.68							
	Seasonal cost	18727.84							
II.	**Surface Irrigation**								
1	Centrifugal pump set (5HP) and accessories	1	13400	13400	20	1340	603	1608	268
	Total annual cost	2479							
	Seasonal cost	740							

APPENDIX- IV : Water requirement of okra crop

Days	Date	Etr	CETr	KC	CWR-100 % (mm)	PE	CPE
1	25-02-2019	3.27		0.7		6.6	
2	26-02-2019	3.32		0.7		6.2	
3	27-02-2019	3.24	6.59	0.7	4.61	5.8	
4	28-02-2019	4.19		0.7	0	6.4	
5	01-03-2019	4.01	7.43	0.7	5.20	6	
6	02-03-2019	3.35		0.7	0	5.4	
7	03-03-2019	3.76	7.36	0.7	5.15	6.6	
8	04-03-2019	3.59		0.7	0	6.2	
9	05-03-2019	3.55	7.35	0.7	5.14	6.5	
10	06-03-2019	3.37		0.7	0	5.8	
11	07-03-2019	3.25	6.92	0.7	4.84	6.2	67.7
12	08-03-2019	3.54		0.7	0	6.8	
13	09-03-2019	3.56	6.79	0.7	4.753	6.4	
14	10-03-2019	3.73		0.7	0	6.8	
15	11-03-2019	3.71	7.29	0.7	5.10	6.2	
16	12-03-2019	3.37		0.7	0	5.8	
17	13-03-2019	3.53	7.08	0.7	4.95	6.6	
18	14-03-2019	3.69		0.7	0	6.4	
19	15-03-2019	3.56	7.22	0.7	5.05	7	
20	16-03-2019	3.73		0.7	0	6.2	
21	17-03-2019	4.36	7.29	0.7	5.10	7.4	
22	18-03-2019	4.46		0.7	0	7	72.6
23	19-03-2019	3.88	8.82	0.7	6.17	7.5	
24	20-03-2019	3.95		0.7	0	7.4	
25	21-03-2019	4.42	7.83	0.7	5.48	6.8	
26	22-03-2019	4.3		0.7	0	7	
27	23-03-2019	4.19	8.72	0.7	6.10	7	
28	24-03-2019	4.17		0.7	0	8	
29	25-03-2019	4.16	8.36	0.7	5.85	7.2	
30	26-03-2019	4.48		0.7	0	7	
31	27-03-2019	4.5	8.64	0.75	6.48	8.2	
32	28-03-2019	4.52		0.75	0	7.9	74
33	29-03-2019	4.6	9.02	0.75	6.76	6.8	
34	30-03-2019	4.2		0.75	0	6.7	
35	31-03-2019	4.8	8.8	0.75	6.6	8	
36	01-04-2019	4.9		0.81	0	8.5	
37	02-04-2019	4.8	9.7	0.81	7.85	8.4	
38	03-04-2019	5.2		0.81	0	7.6	

APPENDIX- IV contd….

Days	Date	Etr	CETr	KC	CWR-100 % (mm)	PE	CPE
39	04-04-2019	5.15	10	0.81	8.10	7.8	
40	05-04-2019	5.3		0.81	0	7.9	
41	06-04-2019	5.18	10.45	0.86	8.98	8.2	69.9
42	07-04-2019	5.49		0.86	0	8.3	
43	08-04-2019	5.58	10.67	0.86	9.17	8.5	
44	09-04-2019	5.14		0.86	0	8	
45	10-04-2019	5.28	10.72	0.86	9.21	8.2	
46	11-04-2019	6		0.92	0	8	
47	12-04-2019	5.9	11.28	0.92	10.37	8.4	
48	13-04-2019	5.38		0.92	0	8.6	
49	14-04-2019	5.52	11.28	0.92	10.37	8.2	66.2
50	15-04-2019	6.1		0.92	0	8.1	
51	16-04-2019	6.25	11.62	0.97	11.27	8	
52	17-04-2019	6.42		0.97	0	7.5	
53	18-04-2019	6.7	12.67	0.97	12.28	7.8	
54	19-04-2019	6.8		0.97	0	8.2	
55	20-04-2019	6.6	13.5	0.97	13.09	8.5	
56	21-04-2019	6.4		0.99	0	8.6	
57	22-04-2019	6.42	13	0.99	12.87	9.2	
58	23-04-2019	6.66		0.99	0	9.4	75.3
59	24-04-2019	6.78	13.08	0.99	12.94	8.8	
60	25-04-2019	6.89		0.99	0	8.4	
61	26-04-2019	7	13.67	1.01	13.80	8	
62	27-04-2019	6.8		1.01	0	8.2	
63	28-04-2019	6.7	13.8	1.01	13.93	7.9	
64	29-04-2019	6.42		1.01	0	7.5	
65	30-04-2019	6.7	13.12	1.01	13.25	8.5	
66	01-05-2019	6.62		1.01	0	9.4	66.7
67	02-05-2019	7.14	13.32	1.01	13.45	9.2	
68	03-05-2019	7.2		1.01	0	9.1	
69	04-05-2019	8.8	14.34	1.01	14.48	9	
70	05-05-2019	7.48		1.01	0	8.6	
71	06-05-2019	7.7	16.28	1.01	16.44	9.6	
72	07-05-2019	7.6		1.01	0	9.5	
73	08-05-2019	7.2	15.3	1.01	15.45	8.7	
74	09-05-2019	7.1		1.01	0	8.4	72.1
75	10-05-2019	6.9	14.3	1.01	14.443	9.8	
76	11-05-2019	6.48		1.01	0	10	

APPENDIX- IV contd….

Days	Date	Etr	CETr	KC	CWR-100 % (mm)	PE	CPE
79	14-05-2019	6.42	13.05	1.01	13.18	9	
80	15-05-2019	6.58		1.01	0	9.2	
81	16-05-2019	6.54	13	1.02	13.26	9.8	66.4
82	17-05-2019	6.9		1.02	0	9.5	
83	18-05-2019	6.7	13.44	1.02	13.70	10	
84	19-05-2019	7.2		1.02	0	8.9	
85	20-05-2019	7.4	13.9	1.02	14.17	9.2	
86	21-05-2019	7.1		1.02	0	9.5	
87	22-05-2019	7.2	14.5	1.02	14.79	9.8	
88	23-05-2019	7.4		1.02	0	9	65.9
89	24-05-2019	7.2	14.6	1.02	14.89	8.8	
90	25-05-2019	7.21		1.02	0	8.9	
91	26-05-2019	7.23	14.41	1.02	14.69	9	
92	27-05-2019	7.45		1.02	0	9.1	
93	28-05-2019	7.1	14.68	1.02	14.97	8.9	
94	29-05-2019	6.91		1.02	0	9.2	
95	30-05-2019	7.24	14.01	1.02	14.29	9.3	72.2
96	31-05-2019	7.12		0.96	0	9.4	
97	01-06-2019	7.35	14.36	0.96	13.78	9.3	
98	02-06-2019	7.8		0.96	0	9.2	
99	03-06-2019	7.6	15.15	0.96	14.54	9.1	
100	04-06-2019	7.9		0.96	0	9.1	
101	05-06-2019	7.8	15.5	0.96	14.88	9	
102	06-06-2019	7.76		0.96	0	8.9	
103	07-06-2019	7.65	15.56	0.96	14.93	9	73
104	08-06-2019	7.2		0.96	0	9.1	
105	09-06-2019	7.1	14.85	0.96	14.256	9.1	
106	10-06-2019	7.3		0.96	0	9.2	
107	11-06-2019	7.4	14.4	0.94	13.536	9.2	
108	12-06-2019	7.5		0.94	0	9.1	
109	13-06-2019	7.6	14.9	0.94	14.006	9.3	
110	14-06-2019	7.12		0.94	0	9.0	
111	15-06-2019	7.32	14.72	0.94	13.8368	8.9	72.9
112	16-06-2019	7.21		0.94	0	8.8	
113	17-06-2019	7.1	14.53	0.94	13.6582	8.9	
114	18-06-2019	6.95		0.94	0	9.0	
115	19-06-2019	7.2	14.05	0.94	13.207	8.8	
				Total	617.35		914.9

8. VITAE

VISHAL RAMESH NAWGHARE

MASTER OF SCIENCE (AGRICULTURE)

IN

IFD-IRRIGATION WATER MANAGEMENT

2021

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