PRECISION FARMING TECHNIQUES IN LONG PEPPER (P*iper longum* L.) UNDER PROTECTED CULTIVATION

by

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THESIS

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DECLARATION

I, **JAYANTH. S.G** (2012-11-185) hereby declare that this thesis entitled **"Precision farming techniques in long pepper (*Piper longum* L.) under protected cultivation"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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We, the undersigned members of the advisory committee of **Mr. JAYANTH.S.G,** a candidate for the degree of **Master of Science in Agriculture,** with major field in Agronomy, agree that the thesis entitled **"PRECISION FARMING TECHNIQUES IN LONG PEPPER (*Piper longum* L.) UNDER PROTECTED CULTIVATION"** may be submitted by Mr. JAYANTH. S. G in partial fulfilment of the requirement for the degree.

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LIST OF ABBREVIATIONS

%	-	Per cent
^{0}C	-	Degree Celsius
BCR	-	Benefit:cost ratio
CD	-	Critical difference
cm	-	Centimetre
cm^2	-	Square centimetre
cm^3	-	Cubic centimetre
CPE	-	Cumulative pan evaporation
Cu	-	Consumptive use
et al	-	And others
FC	-	Field capacity
Fig.	-	Figure
g cc^{-1}	-	Gram per cubiccentimetre
g $plant^{-1}$	-	Gram per plant
g	-	Gram

ha^{-1}	-	Per hectare
K_c	-	Crop coefficient
$kg\ m^{-3}$	-	Kilogram per cubic metre
kg	-	Kilogram
KWm^{-2}	-	Killo watts per meter square
l	-	Litre
m	-	Metre
mm	-	Milli meter
m^2	-	Square metre
m^3	-	Cubic metre
MAP	-	Months after planting
$mg\ g^{-1}$	-	Milli gram per gram
ml	-	Millilitre
mm	-	Millimetre
MSL	-	Mean sea level
N	-	Nitrogen
NS	-	Not significant

PAR	-	Photosynthetically active radiation
PWP	-	Permanent wilting point
RLWC	-	Relative leaf water content
Rs.	-	Rupees
t ha^{-1}	-	Tonnes per hectare
TSR	-	Total solar radiation
W m^{-2}	-	Watts per meter square

INTRODUCTION

INTRODUCTION

Piper longum, popularly known as thippali or long pepper, is an economically important medicinal plant well adapted to the agro climatic situations prevailing in the humid tropics. It is a slender aromatic climber with perennial woody roots. Dried spike is the officinal part commonly used in Ayurvedic and Unani medicines (Aiyer and Kolammal, 1966 and Rahiman *et al.*, 1979). Apart from the spikes, the roots and thicker parts of the stem are cut, dried and used as an important drug (Piplamool) in the above systems of medicines against diseases of respiratory tracts, cardiac and splenic disorders. It is a major constituent of the Ayurvedic drugs prescribed for increasing immunity against AIDS virus. Long pepper is an integral component of 'Trikadu', an ayurvedic preparation, prescribed against several respiratory complaints.

Precision farming is an integrated crop management system that attempts to match the kind and quantities of inputs with the actual crop needs for small areas within a farm field. The objective is optimisation of inputs use to facilitate optimal output resulting in saving of valuable resources like water and energy. New technologies now available allow the concept of precision agriculture to be realized in a practical production setting. Appropriate method of planting for early establishment, proper planting density to enhance yield and yield components, microsite enrichment for rhizosphere modulation, staking for proper leaf disposition, installation of microirrigation systems like drip, micro sprinkler and mist to improve water use efficicency and water productivity, fertigation to enhance nutrient use efficiency, intercropping and multitier cropping for optimum horizontal and vertical utilization of space and shade regulation to maintain ideal habitats can help a long way to achieve higher productivity in long pepper.

Long pepper responds very well to management practices. Root development in long pepper is very slow compared to shoot growth. Providing appropriate rooting medium consisting of a combination of various organic sources of nutrients and bioinoculants can result in proliferation of roots.

In long pepper, vegetative and reproductive growth stages overlap throughout its life cycle and maintenance of an optimum oxygen-nutrient-moisture balance is essential to trigger spike initiation in every leaf axil. Fertigation with liquid organic manures through micro irrigation systems, viz, drip, micro sprinkler or mist ensures proper modulation of rhizosphere to sustain optimum vegetative and reproductive growth. Foliar fertilization has been used as a means of supplying supplement doses of minor and major nutrients, plant hormones, stimulants and other beneficial substances. Observed effects of foliar fertilization include yield increase, resistance to disease and insect pests, improved drought tolerance and plant growth.

One of the key factors influencing spike yield is the number of fruiting branches which is influenced by plant population and disposition of leaves. A spike is produced in the axil of every productive leaf. Increasing planting density and proper disposition of leaves by proper staking / trailing may lead to higher spike production.

Even though, large quantities of dry spikes of long pepper is required every year for meeting the demand of Ayurvedic industries in Kerala, domestic production is quite insufficient to meet the ever increasing demand. Scope for sole cropping of long pepper is limited in Kerala due to high population density and intensive cultivation. The only option available is to introduce long pepper into the existing cropping systems. Long pepper grows well under partial shade (25 to 50 %) in irrigated coconut gardens (Jessykutty and Kiran, 2001). Trials conducted to evaluate the performance of selected geographical races of long pepper resulted in the release of the variety, ‘Viswam’ for intercropping in irrigated coconut gardens (KAU, 1996). Introduction of long pepper in coconut gardens as an intercrop is feasible and remunerative. It helps to augment income from coconut gardens. In order to get optimum yield of spikes, nutrients should be provided in adequate quantities through various sources. Long pepper gardens have to be continuously replenished through periodical application of organic manures, inorganic fertilizers and bio inoculants (Bijily, 2003).

Generally, long pepper is grown in the interspaces of coconut gardens or under partial shade. But the productivity of the crop varies widely with habitats and weather variations. So it is necessary to maintain a favourable microclimate throughout the growth stages of long pepper. Protected cultivation is one of the measures that can be adopted to ensure an ideal habitat for improving the growth and productivity of long pepper. Low cost poly cum shade house constructed in the interspaces of coconut gardens / homesteads can be successfully used for commercial growing of long pepper.

Coconut based cropping systems involving cultivation of compatible crops in the interspaces of coconut and integration with other enterprises offer considerable scope for increasing production and productivity per unit area, time and inputs by more efficient utilization of resources like sunlight, soil, water and labour. In the humid tropics, higher efficiency of utilization of the basic resources of crop production viz. land, solar radiation and water can be achieved by adopting intensive cropping systems (Nelliat, 1973). Introduction of component crops, especially, adoption of multi-storeyed cropping system with compatible crops favours better utilization of resources for augmenting returns besides alleviating inherent soil limitations.

Protected cultivation techniques are widely used for crop production under controlled / partially controlled environment in temperate region and even in arid climates on a commercial basis. They can play vital role in developing countries like India for increasing agricultural production and productivity. Water scarcity, high temperature and low humidity are prevailing during summer in India. These conditions make crop production quite difficult. Plastic films made of low-density polyethylene (LDPE) are commonly used in agriculture as coverings for increasing the yield and quality of agricultural products (Panwar, *et al*. 2009). It is in this context that the present project is designed with the following objective.

i) To develop cost effective agro techniques for improving the quality attributes, productivity and profitability of long pepper under protected cultivation and precision farming systems in the humid tropics

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Long pepper is an economically important medicinal crop widely recommended for commercial mediculture in the humid tropics. It requires specific habitats for satisfactory growth and production. The microclimatic requirements of long pepper match very well with the agro climatic conditions prevailing in the interspaces of middle aged coconut palms of the humid tropics. Hence it is ideally suited for intercropping in irrigated coconut gardens. Commercial mediculture with long pepper by adopting precision farming techniques under protected cultivation in coconut garden yield rich dividends.

The investigation entitled "Precision farming techniques in long pepper under protected cultivation (*Piper longum* Linn.)" was undertaken during May 2013 to April 2014. The objective of the study was to develop cost effective agro techniques for improving the quality attributes, productivity and profitability of long pepper under protected cultivation and precision farming systems in the humid tropics.

The relevant literature relating to the effects of enriched growth medium, staking for proper leaf disposition, micro irrigation systems including drip, micro sprinkler and mist, fertigation with liquid organic manures, intercropping in coconut gardens and cultivation in shade house on the growth, yield components, yield and quality of long pepper and other related crops are reviewed here under.

2.1 Long pepper – Morphology

Piper longum L. belongs to the family Piperaceae. The morphology of long pepper was described by many workers. According to Roxburgh (1832) long pepper is not a climbing plant. It possesses perennial root stock, stem is jointed and creeping, which strikes roots and branches at every node. Leaves are simple, entire, glabrous and alternate, spreading without stipules as described by Krishnamoorthy (1969) and Viswanathan (1995). The female spikes of *Piper longum* is described as solid, cylindrical, tapering above and as solitary, ovoid and fleshy having 1.5 – 2.5 cm in length and 0.5 to 0.7 cm in thickness (Viswanathan, 1995).

2.2 Chemical Composition.

Atal and Banga (1963) identified an alkaloid piplartine from the stem of *Piper longum* and its structure was determined. Anon (1977) isolated piper longmine, piper longuminine, piperine, sesamin and methyl 3, 4, 5- trimethoxy cinnamate from roots.

The studies on the drug obtained from dried roots and thicker part of stem, the piplamool, revealed the presence of pipperine (0.15 – 0. 18%), piplaritine (0.13- 0.2%) and traces of a yellow crystalline alkaloid. Other constituents include triacontane, dihydrostigma sterol, reducing sugars and glycosides. The chemical examination and pharmacological studies on the leaves of *Piper longum* by Manavalan and Singh (1979) revealed the presence of bentriacontane, tricontanol and B-stigma sterol. Sharma *et al.,* (2008) reported the presence of L- tyrosine, L- Cysterine and L- aspartic acid as free amino acids in dried fruits of long pepper.

2.3 Medicinal importance.

The medicinal use of fruits and roots of long pepper in Ayurvedic system of medicine have been described by many workers. Krishnamurthy (1969) reported that long pepper has anti-tubercular activity against *Mycobacterium tuberculosis* H 37 RV strain. This was also reported by Kurup *et al.,* (1979). Phadtare *et al.,* (1996) also reported that long pepper as a mixture in a multiherbal formulation has been found to be very effective against tuberculosis.

In Ayurveda, black pepper, long pepper and ginger are collectively called as '*Trikadu'.* The capacity of this trikadu to increase the bio- availability of other drugs was reported by Sasikumar (2000). Dahankumar *et al.,* (1984), based on clinical studies revealed that thippali is very effective in the treatment of respiratory disorders. According to Stuart (1985), derivative of roots of long pepper called piplamool has the same stimulant tonic and peptic properties as of spikes. Immature berries and stems contain resin, volatile oil, starch, gum, fatty and inorganic matter and an alkaloid piperine. The infusion made from this can be used as stimulant, carminative and an alternative tonic (Nadakarni, 1986). The hepato protective potential of piperine, the active alkaloid in long pepper was reported by Koul and Kapila (1993). Kumar *et al.,* (1979) suggested that the dried unripe fruits can be used as an alternative and decoction of immature fruits and roots can be used in chronic bronchitis, cough and cold. According to Sivarajan and Indira (1995) and Sasikumar (2000), the important formulations using this drug are *abhayaristam, draksharistm, Chyavanoprasam, Pippalyasavam* and *Pancharolan*. Gosh *et al.,* (1996) reported that fruits or *Piper longum* which contains piperine was found to be very effective against intestinal distress (amoebiosis).

2.4 Effect of major nutrients on growth, yield and active ingredients

Plant nutrition is one of the important factors that influence the growth, development and yield of crops. The critical stages of nutrient requirement are initiation of flower primordia, flower emergence, berry formation and development. In case of long pepper the quality of spikes depends on its size and weight, which can very well be improved by application of fertilizers at various growth stages at right quantity (Narayanaswamy, 2009).

The review on response to long pepper is very much limiting. Hence, the response of similar crops to fertilizers is reviewed and presented here

Nitrogen, phosphorous, potassium, calcium and magnesium contents in different parts of four year old pepper vines were estimated by Pillai and Sasikumaran (1976). Nitrogen content was highest in the leaves followed by spikes. Phosphorus was less in the stem. Mohankumar and Cheeran (1981) reported that 75 g nitrogen per plant per year gave the highest yield in black pepper. Sadanandan (1993) reported that a coconut + pepper mixed cropping system with integrated nutrient management in black pepper vines given with

NPK at 100:40:140 g vine^{-1} year^{-1} increased the soil available nutrient and also the over all productivity of black pepper by 172 per cent. Pande *et al.,*(1995) had reported that increased yield of spikes and roots could be achieved in long pepper through application of urea along with organic manure.

Nybe *et al.,*(1989) reported the highest yields in black pepper by application of 50:100:150 NPK g vine^{-1} plus 10 kg green leaves. Studies conducted at the Pepper Research Station, Panniyur in laterite soil showed that for Panniyur pepper, the application of 50 g N: 50 g P_2O_5: 200 g K_2O vine^{-1} in two split doses has recorded highest yields. Whereas, Sadanandan (1993) found that 140 kg N: 55 kg P_2O_5: 270 kg K_2O year^{-1} ha^{-1} was the best dose of nutrients for adult pepper vines for production of maximum yields.

Maithi *et al.,* (1997) recorded significantly highest betel leaf yield, number of branches and vine elongation when N at 200 kg ha^{-1} was applied in 12 splits. Jahan (1999) recorded significant increase in yield of betel vine when organic and chemical fertilizers were applied in the ratio of 2:1.

Pande *et al.,* (1995) reported that increased yield of spikes and roots could be achieved in long pepper with the application of urea along with organic manure. Sheela (1996) also emphasized the application of 20 tonnes of organic manure and 30:30:60 kg NPK per hectare for optimum yield in long pepper.

Integrated nutrient management system involving incorporation of vermicompost @ 6.25 t ha^{-1} year^{-1}, addition of NPK @ 30 : 30 : 60 kg ha^{-1} year^{-1} and combined application of bioinoculants, viz, Azospirillum, fluorescent Pseudomonas and AM fungi was found favourable for enhancing both total fresh and dry spike yield and total alkaloid production in long pepper under partial shade (Bijily, 2003).

2.4.1 Liquid organic manures:

Foliar sprays with liquid organic manures exhibited their significance over control and enhanced growth and productivity.

2.4.1.1 Vermiwash :

Vermiwash is very useful as foliar spray to enhance the plant growth and yield. Besides, it checks the development of diseases. It is a collection of excretory products and mucus secretions of earthworm along with nutrients from the soil organic molecules (Ismail and Pramoth, 1995). Vermiwash spray is also used as a prophylactic measures for repelling and controlling pests (Sebastian and Lourduraj, 2007).

Among the various organic manures and foliar nutrients, application of vermicompost @ 5 t ha^{-1} and vermiwash 1:5 dilution increases quality attributes in general (Umamaheshwari and Haripriya, 2008).

2.4.1.2 Panchagavya:

Panchagavya is applied to safeguard plant and soil microbes besides increasing crop productivity. Presence of growth regulating substances such as IAA, GA3, cytokinin and essential plant nutrients in panchagavya promotes plant growth. Effective microorganisms predominantly lactic acid bacteria, certain beneficial biofertilizers and plant protection substances are detected in panchagavya (Pandian, 2000). Panchagavya has the properties of both fertilizer and biopesticide and increase the economic yield of the crops (Sebastian, 2007).

2.4.1.3 Jeevamrutha

Jeevamrutha is a mixture of cowdung, cows urine, black gram flour, jaggery and one hand full of soil. It is not a liquid manure to supply large quantities of nutrients but it is an enriched liquid bacterial culture along with small quantities of nutrients like nitrogen, phosphorus, and potassium besides many micronutrients. The initial level of useful bacteria like N-fixing and P-solubalizing get proliferated four-five times during incubation. Repeated application of jeevamrutha enhances the biological activity in the soil and helps for faster decomposition of carbonaceous material releasing the plant nutrients. Jeevamrutha application improves the soil fertility and other physical characters of the soil ensuring sustainable crop yields in the long run (Mukundjoshi *et al*., 2011).

2.4.1.4 Effect of liquid organic manures

Studies condudcted to test the efficacy of vermiwash and cowdung on morpho-physiological parameters of soyabean (*Glycine max* L.) revealed that foliar sprays of vermiwash and cowdung were effective in increasing plant height, number and dry weight of root nodules, leaf area, total dry matter production, AGR, RGR and yield when compared with control and other treatments (Deotale, *et al*. 2008).

Humic sources (cow dung and vermiwash) exert their influence on foliar transport in a number of ways. The foliar application enhances the absorption of nutrients by the leaf at site of application resulting in enhanced vegetative growth (Deotale, *et al*. 2008). The above observations are in consonance with the findings of Chen and Solovitch (2003). They found that foliar application of humic substances enhanced shoot growth. Foliar application of humic acid fastens the absorption of N and P through foliage and induces nodule formation and rhizobial activity (Tamhane *et al*., 1965).

Observed effects of foliar fertilization include yield increases, resistance to disease and insect pests, improved drought tolerance and plant growth. Panchagavya was found to to enhance the biological efficiency of crop plants and the quality of fruits and vegetables. It was found to have the properties of both fertilizer and bio-pesticide and increased the economic yield of crops such as rice, green gram, sunflower, turmeric, moringa and coleus. Vermiwash application is reported to increase the growth and yield of crops such as marigold, chrysanthemum and tomato. Vermiwash is also used as prophylactic measures for controlling pests and as a repellent (Sebastian, 2007).

Hot pepper (*Capsicum annum*) showed appreciable variation in the growth, yield and quality attributes in realation to various sources of organic manures and foliar nutrients. Among various organic manures tested, application of vermicompost @ 5t ha^{-1} and groundnut cake @ 250 kg ha^{-1} along with panchakavya-3% for 4 times recorded the highest plant height, maximum number of branches, maximum number of fruits, highest fruit length, maximum fruit girth and highest dry fruit yield which was comparable with inorganic fertilizers (Sundaram and Udayakumar, 2002).

In hot pepper, application of FYM @ 25t ha^{-1}, neem cake @ 500 kg ha^{-1} along with vermiwash at 1:5 dilution was found beneficial for improving ascorbic acid and capsaicin contents (Chavan *et al*., 1997). Moreover, continuous supply of P from vermiwash solution and subsequent uptake by the plants would have resulted in bettr quality attributes. It is evident that, P plays an important role in improving absorbic acid content of fruits (Niranjana and Devi, 1990).

2.5 Irrigation management

There is good potential for adoption of drip irrigation and use of water soluble fertilizers with drip system i.e, fertigation technique for achieving better productivity and quality in different crops. In drip irrigation method, water tension remained low as compared to surface irrigation. This is one of the main reasons for getting higher equivalent yield under drip irrigation method. Maximum weed density and dry weight of weeds was also noticed under surface irrigation of 6 cm depth and it was significantly higher over all the levels of drip irrigation. Less weed density and dry weight of weeds might be due to partial wetting of soil and irrigation method. Maximum B:C ratio was accrued from drip irrigation at 100% CPE, followed by drip irrigation at 80% PE (Ajitkumar *et al*., 2013) .

Adequate supply of soil moisture can maintain optimum turgor potential which opens the stomatal aperture for gaseous exchange and leads to higher photosynthetic rate and ultimately increases plant growth characters and yield. This was confirmed with no stress condition (1.0 CPE), which provided adequate moisture for growth and development of long pepper (Manjunatha *et al*., 2007).

2.5.1 Drip system

Application of fertilizers through drip irrigation system (fertigation) can reduce fertilizer usage, minimize leaching by rain and excessive irrigation, maximize the fertilizer use efficiency, allows flexibility in timing fertilizer application, and reduces the labour required for applying fertilizer (Lewis, 2001).

2.5.1.1 Effect of drip irrigation on soil moisture characteristics

Trickle irrigation operates on the basis of a constantly maintained wetted zone around plant roots and wetted area under a point source (dripper) which are greatly affected by the application rate and duration of irrigation. With lower application rate of 5 l hr^{-1} for longer time (2 hrs per day), the depth of wetting was more when compared to higher application rate of 30 l $hr^{-1}$for shorter time (20 minutes per day) (Rekha and Mahavishnan, 2008). Hachum *et al*., (1976) reported that under an isolate dripper, the vertical component of wetted zone becomes larger and the horizontal component becomes smaller with decrease in discharge rate, the extent of wetted zone is determined by the emitter spacing (Keller and Karmeli, 1975). Increase in volume of water application resulted in increased wetted soil volume and discharge rate reduced vertical movement of wetting zone and increased horizontal movement (Ahluwalia, 1993). With lower discharge rates, the leading edge of wetting profiles were found to have a narrow shape (carrot shape) and become rounded (onion shape) with higher discharge rate (4 -6 l hr^{-1}).

2.5.1.2 Effect of drip irrigation on soil moisture content

Hendrickx and Wierenga (1990) pointed out that variability in soil water tension was related to the method of irrigation slow and frequent watering eliminated wide fluctuations in soil moisture under drip irrigation. Bucks *et al*., (1984) reported that the soil water content in a portion of plant root zone remained fairly constant because irrigation water was applied slowly and frequently at a predetermined rate. Water retention curve drawn by Baryosef and Sheikhoslami (1980) showed constant wate rretention in soil under drip irrigation. Bharadwaj *et* *al.* (1995) reported that the soil water distribution in both 0 to 0.15 m and 0.15 to 0.30 m depths was uniform under drip irrigation and decreased as the soil depth and horizontal distance from the dripper increased.

2.5.1.3 Effect of drip irrigation on growth parameters

Drip irrigation at 80 per cent pan evaporation resulted in taller plants, more number of branches, higher leaf area index and dry matter production of bhindi compared to surface irrigation at 35, 60 and 85 mm CPE (Abrol and Dixit, 1972). According to Tiwari *et al*.(1998) drip irrigation in bhindi at 0.6, 0.8 and 1.0 VD (volume of irrigation requirement through drip irrigation) resulted in maximum plant height, leaf area index, crop growth rate, relative growth rate, net assimilation rate and dry matter production over furrow irrigated crop. Punamhoro *et al*. (2003) revealed that bhindi irrigated through drum kit and bucket kit system of drip irrigation recorded tallest plants, maximum leaf area, number of branches and dry matter production over rest of the irrigation methods (micro sprinkler, over head sprinkler, flood, check basin, furrow irrigation.

2.5.1.4 Effect of drip irrigation on yield attributes and yield

Gorantiwar *et al*. (1991) reported that the number of pods plant^{-1}, pod length, pod weight and pod yield of bhindi were significantly higher in drip irrigation (water applied at 40, 60, 80 and 100 % wetted area) over furrow irrigation and the increase in yield was 35 to 45 per cent. Jaikumaran and Nandini (2001) observed no significant difference in yields of bhindi irrigated. The improved fertilizer application efficiency in drip fertigation was as a result of small and controlled amount of fertilizers applied as per the crop requirement in contrast to large amount of fertilizer placed on the bed at the beginning of the season (Dangler and Locascio, 1990). Mohan and Arumugam (1994) stated that application of 50 per cent recommended dose of N through biwall subsurface irrigation system recorded the highest nitrogen use efficiency.

In *Coleus forskohlii*, 14.7 to 48.1 per cent water saving due to drip-fertigation compared to surface irrigation and soil application of fertilizer was reported (Kannan, 2008). Drip irrigation was found superior to surface irrigation in okra. Yields and yield components increased with increasing fertilizer rate by fertigation, but 75% was not significantly different from 100 or 125%, which were all superior to conventional application (Tumbare *et al.*, 1999).

2.6 Staking

Staking is one of the key factors influencing spike yield in long pepper. Vertical training or staking significantly increased the marketable yield, improved quality, increased fruit set, increased fruit length and decreased fruit rot incidence and yield per m^2 in tomato. Staked plants had greater plant weight at harvest, and greater weight and dimensions of leaves than unstaked plants (Hanna and Adams, 1984).

Growth characters and yield attributes of black pepper trained on *Moringa oleifera*, *Erythrina stricta* and *Gliricidia sepium*, were not significantly affected by different standards. However the vine length, number of leaves, number of nodes, leaf area index and number of spikes increased (Kumar *et al*., 1979). Field studies in sweet potato showed that there was no flowering in non-staked plants (Martin, 1988). Yam species (*Dioscorea* spp.) requires support stakes in order to give good yields. Yield increases of 33-85% or more have been recorded after staking (Obiazi, 1995).

Methods of training tomato plants (staked vs. unstaked or pruned vs. unpruned) or growing under conditions of reduced light or moisture did not alter the fruit acid content (Mathews *et al.,* 1996).

Okonmah (2011) reported that plant growth, yield and yield components were better under staking in cucumber than no staking and best with five meter raised platform staking method since the number of leaves, flowering, pollination and fruiting were well enhanced due to better display to sunlight.

In African yam bean, highest seed yield was observed due to staking compared to nonstaking (Ogah, 2003). It has been reported that African yam bean is a vigorous, herbaceous, climbing leguminous plant whose height could be up to 1.5-2 m. Hence, as a climbing crop, it needs a stake for proper vegetative growth. The vegetative growing stage is characterized with the profuse production of trifoliate leaves which is required for an enhanced seed yield (Milneredhead and Polhill, 1971). Yield reductions observed on all the accessions under non-staking condition has been reported by earlier researchers (Adeniyan *et al*., 2007). According to them, when African yam bean is not staked it lacks the support given by the stake material which assist it in repositioning the leaves for adequate sunlight it require for proper growth.

2.7 Protected cultivation

Light is essential for plant growth and development as it interacts powerfully with other environmental variables to regulate plant responses in relation to the environment.

2.7.1 Effect of shade on the performance of crop

Protected cultivation can eliminate unfavourable conditions that prevent plants from achieving their production potential. Light hardens plants off against growth-inhibiting effects of mechanical stresses in protected environments and likely contributes to hardening in the field. Growth-dynamic and gas-exchange metrics reveal interactions of light level, CO_2 concentration, temperature, and nitrogen nutrition in stimulating crop productivity and nutritional composition while saving energy for lighting. Intracanopy lighting of planophile crops growing in controlled environments with low-power lamps overcomes aspects of dense plantings and mutual shading that occur with overhead lighting (Mitchell, 2012).

Shade net can be commercially exploited for successful year round cultivation of high value thermo sensitive vegetable like sweet pepper. It is concluded that 35% shade is most suitable for cultivating sweet pepper under tropical conditions (Franscescangeli *et al*., 1994).

Prevailing weather parameters significantly influenced the yield components and yield. More number of fruits per plant was observed under 35 per cent shade than open and 50 per cent shade in sweet pepper cultivar Indra. This is in line with the findings of Aidy (1986) who reported that tomato plants grown under shade tend to produce higher fruit yield than those in open field. The reduction in number of fruits per plant under open field condition might be due to poor fruit set under high temperature and low humidity. Fruits in 50 % shaded plots were significantly longer than open field conditions as these conditions might have influenced the availability of auxin to the developing ovary (Priya *et al*., 2002a). Reduction in fruit size under open condition could be ascribed to the reduced supply of assimilates to developing sink and excess respiration (Cockshull *et al*., 1992). Fruits girth was more in shaded plots as compared to open field condition in sweet pepper cultivar with the highest value at fifty percent shade. This might be due to favourable temperature inside the shade house which would have increased both linear and circumferential growth of fruit (Priya *et al*., 2002b). Reduced fruit girth under open condition could be attributed to high temperature and low relative humidity at the time of flowering leading to increased transpiration and exhaustion of water.

The yield of sweet pepper per ha was significantly superior at 35 per cent shade in sweet pepper than open and fifty per cent shade. Similar results were observed by Aidy (1986) who stated that vegetables under shade tended to produce higher fruit yield than those in open, but such tendency was reduced with increase in amount of shade. Increase yield under shade might be due to increased number of branches per plant and the highest number of fruitrs per plant. Similar results were reported by Diez *et al.*, (1986) who observed increase in tomato production under plastic house condition due to greater number of fruits per plant and number of fruits per cluster than in open. The poor yield under open field condition in sweet pepper might be due to high temperature. The plants were able to grow fast under high temperature, which promotes the earliness but decreases the total yield. Ryliski (1986) reported that pepper plants in the open field set fruit at lower nodes and restricted further vegetative growth and flowering.

2.7.2 Effect of shade on physiological parameters

The physiological parameters indicate the efficiency of the plant in terms of yield. The damage on cell membrane integrity was measured in terms of electrolyte leakage from the cell. The percentage of electrolyte leakage was the highest (less membrane integrity) under open field condition in Kohinoor and lowest under 35% shade in sweet pepper cultivar Indra. This was due to extremes of temperature in open field which increased the percentage of leakage in, followed with reduction in photosynthetic efficiency and respiration rate and accelerated senescence. This is in accordance with the findings of Leopold *et al.*, (1981). The highest yield under shade might be due to reduced leakage percentage. Similar result was observed by Kavitha (2005) in tomato. The reduction in leaf relative water content under open field condition could be attributed to increased light intensity, transpiration rate, and reduced stomatal diffusive resistance. Reduction in leaf water content might be the reason for poor yield under open field condition, Slayter (1955), who observed that reduction of relative leaf water content in plants by five percent may lead to a reduction in photosynthetic efficiency by 40-60%.

Piper longum plants grow under 50% shade (maximum instantaneous light intensity 850 µmol m^{-2} s^{-1}) performed well compared to plants grown under 25 and 75% shade respectively. Planting medium comprising sand, topsoil and farmyard manure mixed in the ratio of 1:1:1 was found to be the best substratum for the growth of *P. longum* plants. Plants raised from vertically grown branches produced fruits earlier compared to those from horizontally grown branches. However, nearly 50% of fruits were shed from the mother plant about 22 days after their emergence (Etampawala *et al*., 2002).

The shoot of *P.longum* grown under medium shade condition were significantly taller compared to those grown under low shade and deep shade.

Under medium shade, plant produced significantly higher number of leaves compared to those grown under medium and deep shade. The root collar diameter in plants grown under deep shade was significantly lower than that in low and medium shade, where they were more or less similar. The chlorophyll content was highest in plant grown under medium shade and lower in those grown under low and deep shade (Etampawala et al., 2002).

2.8 Intercropping long pepper in coconut garden

Multispecies and multistoried cropping systems ensure maximum resource capture and use leading to higher yield per unit area of soil, water and light. Improvement in soil properties and biological activities in the root region due to intercropping, results in the modification of soil environment for the benefit of the plant growth (Maheswarappa *et al.,* 1998). Effective utilization of available space, both horizontally and vertically, is the modem concept of cropping system. Growing coconut as monocrop is not the most efficient way of using natural resources. Adoption of coconut based multiple cropping system emerges as the viable way for improving the economic status of coconut farmers. Studies revealed that natural resources *i.e.,* soil, water, air space and solar radiation are not fully utilized under the spacing schedule 7.5 m ·x 7.5 m. Further, in India, coconut is primarily a crop of small and marginal farmers (Rethinam, 2001). A well designed high density multistoreyed crop model suited to a given agro-climatic situation generates greater biomass output, yields more economic produce, generates steady and higher total income, additional employment opportunities for family labours and meets diversified needs of the farmers, such as food, fruit, vegetables, fuel, etc (Rethinam, 2001; Ghosh and Hore, 2007; Hore *et al.* 2007).

Intercropping studies conducted at coastal Kerala and other parts of India have indicated the possibility of growing shade tolerant medicinal and aromatic crops under partial shade of coconut (Maheshwarappa, 1997). Long pepper grown in the interspaces of coconut garden resulted in higher yield per unit area.

Improvement in the soil properties and biological activities in the root region have been noticed due to intercropping (Maheswarappa *et al.,* 1997).

Integrated nutrient management system involving incorporation of vermicompost @ 6.25 t ha^{-1} $year^{-1}$, addition of NPK @ 30:30:60 kg ha^{-1} $year^{-}$ and combined inoculation of bioinoculants, viz, Azospirillum + Fluorescent pseudomonas + AM fungi was found favourable for enhancing both total fresh and dry spike yield and total alkaloid production for intercropped long pepper in coconut garden (Anilkumar *et al*., 2009).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

Investigations on "Precision farming technique in long pepper (*Piper longum* Linn.) under protected cultivation" was carried out at the College of Agriculture, Padannakkad, Kasaragod, Kerala during May2013- April 2014 to develop cost effective agro techniques for improving the quality attributes, productivity and profitability of long pepper. The materials utilized and the methodology followed for the experiment are presented in this chapter.

3.1 MATERIALS

3.1. Location

The Experiment was conducted at the Instructional Farm attached to the College of Agriculture, Padannakkad. The Farm is located at 12^0 $20^,$ $30^{,,}$ N latitude and 75^0 $04^,$ $15^{,,}$ E longitude at an altitude of 20 m above MSL.

3.1.1. Cropping history

The experiment was conducted in the interspaces of middle aged coconut palms. The interspace was lying vacant for the last three years. The soil of the experimental site is sandy (Hosdurg series). The mechanical composition and moisture characteristics of the soil are furnished in Table 1. Its chemical properties are summarized in Table 2.

3.1.2. Crop and variety

Piper longum Linn. variety 'Viswam' released from Kerala Agriculture University was used for the study. The plant is an under shrub with erect stem and slender creeping branches. Leaves are simple, alternate, stipulate and petiolate according to their position on the plant. Spikes are the fruits with 3-5 cm length and 2.5 cm diameter. Dry female spikes are the economic part of the crop.

3.1.3. Climate and season

The weather data recorded during May 2013- April 2014 are given in Appendix 1 and graphically presented in Figure 1. The abstract of the weather data is given in Table 3.

Table 1. Mechanical composition and moisture characteristics of soil

Particulars	Content	Method used
A. Mechanical composition		
Coarse sand, %	30.28	Bouyoucos Hydrometer Method (Bouyoucos, 1962)
Fine sand, %	57.65	
Silt , %	7.50	
Clay, %	4.57	
B. Soil moisture characteristics		
Particle density, g cc^{-1}	2.16	Pycnometer method (Black , 1965)
Bulk density, g cc^{-1}	1.34	
Maximum Water holding capacity, % (W/W)	21.30	
Porosity ,% (V/V)	47	Core method (Gupta and Dakshinamoorthi, 1980)
Field capacity, %(w/w)	16	
Permanent wilting point, % (w/w)	10	

Table 2. Chemical properties of soil

Particulars	Content	Method
Organic carbon, %	0.38	Wakley and black titration method (Jackson, 1973)
Organic matter, %	0.5%	
Available nitrogen, kg/ha	52.8	Alkaline KMnO4 method (Subbaih and Asija, 1956)
Available phosphorus, kg/ha	14.3	Braya's colorimetric method (Jackson, 1973)
Available potassium, kg/ha	22.1	Ammonium acetate method (Jackson, 1973)
Soil reaction, pH	5.3	1:2.5 soil suspension using pHMeter with glass electrode (Jackson, 1973)

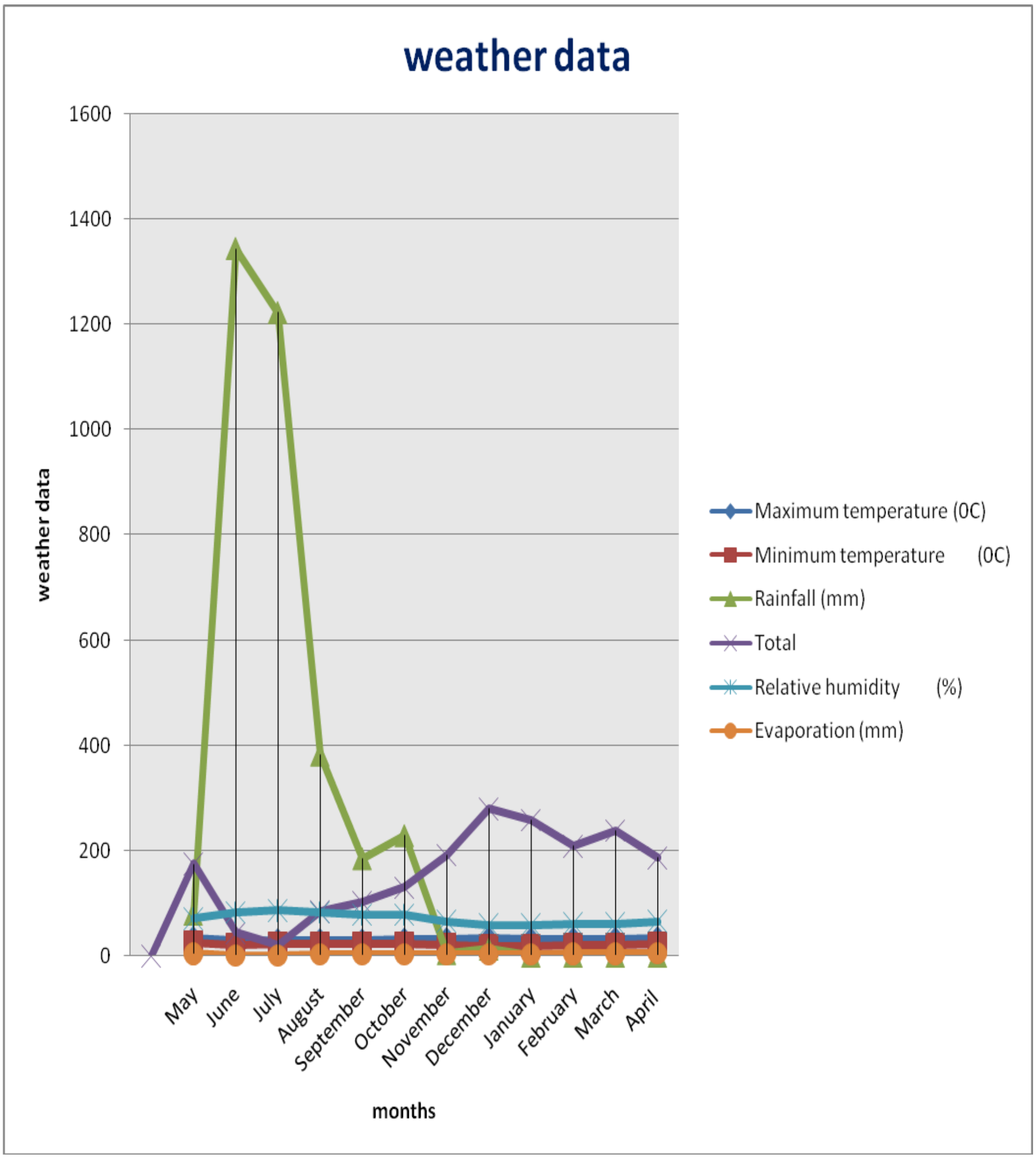

Fig.1 Weather data during the crop period

Table 3. Abstract of weather data during the experimental period

Weather parameters	Range	Mean
Maximum temperature, ^{0}C	29.90- 34.58	32.2
Minimum temperature, ^{0}C	19.69-26.23	22.9
Annual rainfall, mm	………	3511.73
Relative humidity, %	58.30 – 86.36	70.67
Daily evaporation, mm	1.68-5.20	3.48

During the experimental period, the daily maximum temperature ranged from 29.90^{0}C to 34.58^{0}C, with a mean of 32.2^{0}C. The total rainfall recorded during the period was 3511.7 mm. The period from January to April received no rain. The peak rainfall season coincided with June and July months.

The mean relative humidity ranged from 58.30 to 86.36 with a mean of 70.67 per cent. The relative humidity was low during December and January (58.30 to 58.81 per cent with a mean of 70.67 per cent) and high during June, July and August months (ranged from 86 to 90 per cent).

The mean evaporation ranged from 1.68 to 5.20 with a mean of 3.48. The monthly evaporation was highest (5.0 to 5.2) during March to April months and lowest during June and July months.

The bright sunshine hours per month ranged from 19.1 to 238.5 with a mean of 159.95. Sunshine hours were low during June and July months ranging from 19.1 to 43.4 hr and high during December to March (Ranging from 238.5 to 279.6). The area enjoys a warm humid tropical climate.

3.2. METHODS

3.2.1. Design and Layout

Design : RBD

Treatments : 14

Replication : 2

Spacing : 60 x 50

Plot size : 3.6 x 2.5

Duration : one year

T1-Planting in trenches filled with enriched growth medium + Staking + Fertigation through drip system

T2- Planting in trenches filled with enriched growth medium + Staking + Fertigation through micro sprinkler

T3- Planting in trenches filled with enriched growth medium + Without Staking + Fertigation through drip system

T4- Planting in trenches filled with enriched growth medium + Without Staking + Fertigation through micro sprinkler

T5- T1 + Planting in hanging pots and fertigation through mist

T6- T2 + Planting in hanging pots and fertigation through mist

T7- T3 + Planting in hanging pots and fertigation through mist

T8- T4 + Planting in hanging pots and fertigation through mist

T9- Planting in trenches filled with potting mixture + Without staking + Life saving irrigation (Control)

T10 - T1 Under partial shade

T11- T2 Under partial shade

T12- T3 Under partial shade

T13- T4 Under partial shade

T14- Planting in trenches filled with potting mixture + Without staking + Life saving irrigation under partial shade (Control)

3.3 Lay out of the experiment

R- I

T5	T3	T6	T7	T2	T8	T9	T1	T4	T10	T13	T14	T11	T12

R- II

T12	**T11**	**T14**	**T13**	**T10**	**T4**	**T1**	**T9**	**T8**	**T2**	**T7**	**T6**	**T3**	**T5**

A) Linear trenches

B) Green leaf manuring

C) Structure of shade house

D) Micro site enrichment

Plate.1 Micro site enrichment and erection of shade house

3.4 Production of rooted long pepper saplings

Long pepper vines were cut into pieces of 20 cm length and planted in polythene bags filled with potting mixture (1:1:1 mixture of sand: soil: cowdung). Polythene bags were kept under partial shade for two months and watered once in two days. Saplings attained four leaf stage at the time of planting in the main field.

3.4.1 Preparation of enriched growth media

Enriched growth medium was prepared by mixing dry powdered cowdung : vermi compost: composted coirpith : bone meal in 1:1:1:1 proportion which was later enriched with *Trichoderma, Azospirillum, and Pseudomonas*.

3.4.2 Planting

Trenches of 3.6 m length, 30 cm width and 45 cm depth were taken, mulched the bottom with dry leaves to a height of 10 cm, filled with enriched growth medium and mixed with surface soil. Long pepper saplings were planted in the trenches at a spacing of 60 x 40 cm @ one sapling per hill.

3.4.3. Imposition of treatments

Planting of long pepper saplings was carried out as explained in section 3.4.2

3.4.3.1 Staking

A cassava stem of one metre length was erected at a distance of 15 cm from the base of each long pepper plant and the growing vine was trailed on to it. Cassava was defoliated at fortnightly intervals to avoid competition with long pepper.

3.4.3.2 Hanging pots

Plastic pots of size of 500 cm^3 was filled with enriched growth medium prepared as explained under section 3.4.1, planted long pepper saplings @ one per pot and tied to the roof of the shade house with plastic rope as shown in Plate 2.

3.4.3.3 Shade house

A shade house was erected in the interspaces of two rows of coconut palms standing at row distance 7.5 m and plant to plant distance of 7.5 m. 50 per cent shade net was used to ensure proper shade for the crop.

3.4.3.4 Irrigation

Three methods of irrigation namely drip, micro sprinkler and mist were installed as per the technical programme. Drip lateral line was laid out for each long pepper row and one emitter of capacity 5 litre per hour was provided for each plant at a spacing of 60 x 50 cm. A microsprinkler of capacity 44 litre per hour was erected in each plot for covering an area of 9 m^2. Mist irrigation was provided for long pepper in hanging pots and mist outlets were installed on laterals passing over the hanging pots @ two per plot.

3.4.3.5 Fertigation

A fertilizer applicator was installed in the system to discharge liquid organic manures. A filtration unit was also provided to ward off unwanted items for avoiding emitter clogging. Rotational application of liquid organic manures such as vermiwash, panchagavya and jeevamrutha was effected. The liquid organic manures were prepared as detailed below and filled in to the fertigation tank and discharged through drip, micro sprinkler and mist irrigation as per the technical programme.

3.4.3.6 Preparation of vermiwash

The protocol standardized by KAU was followed for the preparation of vermi wash (KAU, 2011).

3.4.3.7 Preparation of panchagavya

The standard procedure (cowdung + cows urine + cow ghee + cows milk + cow curd + jaggery) prescribed by the (KAU, 2011) was followed for the preparation of Panchagavya.

3.4.3.8 Preparation of jeevamrutha

The procedure followed by progressive farmers (cow dung + cow urine + black sugar + black gram + one hand full of soil) was followed (KAU, 2011).

3.5 Irrigation

The crop was irrigated from september to may . A pre-treatment irrigation was given to bring the soil to field capacity. The quantity of water applied per plot was calculated by taking the depth of irrigation as 6 cm. The volume of water to be applied to bring the soil to field capacity was calculated and the details are shown below.

d = depth of water applied in cm.

dw = readily available moisture (%)

Volume of water per plot = depth of water applied in m x area irrigated in m^2.

= 0.10 m^3

107.73 litre of water per plot was discharged through micro irrigation system during one irrigation. The details of irrigation given are presented in Table 4.

Table 4. Details of irrigation given during the experimental period

Treatments	No of irrigations	Pre-treatment irrigation (mm)	Quantity of water applied (mm)	Effective rainfall (mm)	Total water requirement (mm)
T_1	105	540	56700	1200	57900
T_2	105	540	56700	1200	57900
T_3	105	540	56700	1200	57900
T_4	105	540	56700	1200	57900
T_5	105	675	70875	1200	72075
T_6	105	675	70875	1200	72075
T_7	105	675	70875	1200	72075
T_8	105	675	70875	1200	72075
T_9	14	540	7560	1100	8860
T_{10}	105	540	56700	1400	58100
T_{11}	105	540	56700	1400	58100
T_{12}	105	540	56700	1400	58100
T_{13}	105	540	56700	1400	58100
T_{14}	14	540	7560	1050	8960

3.6 Post planting care

All the saplings planted established very well. Nutrient management and irrigation scheduling were carried out as per the technical programme. Weeding was carried out twice at 2 and 4 MAP as the canopy coverage was sparse. There was no incidence of any pest or disease. The crop was raised following the package of practices recommendations of Kerala Agricultural University (KAU, 2011).

3.6.1 Harvesting

The crop was harvested at bimonthly intervals commencing from 6 MAP and a total of four harvests were carried out during the experimental period.

3.7 OBSERVATIONS

Observations were taken after 6 MAP coinciding with spike harvest. Five plants per plot were selected at random for recording all observation unless otherwise specified. The methods followed for recording observation are furnished below.

3.7.1. Growth characters

Growth characters were recorded at monthly intervals from 7 MAP for a period of 12 months from randomly selected observation plants and mean values worked out.

3.7.1.1 Vine length

The length of the longest vine was taken from the base of the plant to the tip of the emerging leaf using a meter scale. It was expressed in centimeters.

3.7.1.2 Number of leaves

The total number of leaves on the vine was counted and recorded.

3.7.1.3 Leaf area

Leaf area was found out using a leaf area meter at 10 and 12 MAP.

3.7.2. Root Parameter

Representative samples were uprooted at monthly intervals from 7 MAP. They were thoroughly washed in running water to remove the adhering soil particles. The procedures described by Mishra and Ahmed (1989) were followed for the estimation of root parameters.

3.7.2.1 Root number

The whole plant was uprooted and the total number of roots were counted.

3.7.2.2 Root weight

The roots were washed, cleaned and dried in an oven at 75^0C for about 10-20 hrs. It was expressed as g $plant^{-1}$.

3.7.2.3 Root length

The roots were placed in a flat glass dish containing small amount of water. Graph paper was placed under the dish. Roots were straightened by forceps so that they did not overlap. It was expressed in cm and held in position by glass plate.

3.7.2.4 Root spread

Root spread was estimated using a graph paper.

3.7.3. Physiological and bio chemical parameters

For recording physiological parameters third fully opened leaf from the top was taken as the index leaf.

3.7.3.1. Relative leaf water content (RWC)

The method proposed by Weatherley (1950), which was later modified and described in detail by Slatyer and Barrs (1965) was used to determine relative leaf water content and expressed in per cent.

Relative water content on leaf was calculated detailed below.

$$\text{RWC} = \frac{\text{Fresh weight- Dry weight}}{\text{Turgid weight – Dry weight}} \text{ X 100}$$

3.7.3.2. Total dry matter production

The plants were uprooted and the roots and shoot portions separated out in each sampling and dried to a constant weight at 80^{0}C in a hot air oven. The dry weight of roots and shoot portions were recorded separately and expressed in g $plant^{-1}$. Total dry matter production was worked out from shoot and root dry matter.

3.7.3.3 Chlorophyll content

The procedure described by Swarajkumari (2007) was followed for the estimation of leaf chlorophyll a and b.

3.7.3.4 Carotenoids

The procedure described by Swarajkumari (2007) was followed for the estimation of carotenoids.

3.7.4. Soil moisture studies

3.7.4.1 Soil moisture

Soil sampling was done using a screw auger at a distance of 15 cm away from the base of the plant to a depth of 20 cm just before and after irrigation and the soil moisture worked out gravimetrically.

3.7.4.2 Consumptive use

$$Cu = \sum_1^n (Ep \times 0.6) + \sum_1^n \frac{(Mai - Mbi)}{100} \times Asi \times Di \times ER$$

Where Cu= Consumptive use of water in mm

Ep = Pan evaporation from USWB class a open pan evaporimeter from the date of irrigation to the date of soil sampling after irrigation.

0.6 = A constant used for obtaining ET value from the pan evaporation value for the given period of time.

Mai = Percentage of soil moisture (W/W) of the ith layer of soil at the time of sampling after irrigation.

Mbi = Percentage of soil moisture (W/W) of the ith layer of soil at the time of sampling before irrigation.

Asi = Apparent specific gravity of ith layer of soil, gcc^{-1}.

Di = Depth of ith layer of soil, gcc^{-1}.

ER = Effective rainfall within the season

n = Number of soil layer

N= Number of days between irrigation and post irrigation soil sampling.

3.7.4.3 Irrigation requirement

Irrigation requirement was estimated by directly adding the quantity of water used for irrigation in each treatment.

3.7.4.5 Water use efficiency

Crop water use efficiency (CWUE) and field water use efficiency (FWUE) were worked out using the following formula and expressed as g M^3.

$$CWUE = \frac{\text{Yield}}{\text{Consumptive use}}$$

$$FWUE = \frac{\text{Yield}}{\text{Total water requirement}}$$

3.7.4.6 Water productivity (WP)

Water productivity was estimated using the formula proposed by Kijne *et al.*, (2003) and expressed as g M^{-3}.

$$WP = \frac{\text{Total biomass}}{\text{Total water depleted}}$$

3.7.4.7 *Crop Coefficient (Kc)*

Crop coefficient was worked out by dividing the consumptive use during a given period by pan evaporation value during that period.

3.8 Yield and yield attributing characters

3.8.1. Spike number

Total number of spikes per plant was counted from four random plants and mean worked out.

3.8.1.1 Fresh and dry spike yield

The fresh weight of spikes was recorded immediately after every harvest. The spikes were air dried for 1-2 weeks and dry weight recorded. Spike yield was expressed in kg ha^{-1}.

3.8.1.2 Dry spike yield

1-2 weeks after harvesting, dry weight was recorded.

3.9 Laboratory analysis

3.9.1 Plant analysis

The plant samples are dried in oven. After drying crushed .samples were analysed for N, P, K by adopting standard procedures.

Nitrogen content was estimated by using microkjeldhal method (Jackson, 1973). Phosphorus content using vanado molybdo phosphoric yellow colour method (Jackson, 1973) and potassium content using flame photometer method (Piper, 1976).

3.9.2 Biochemical analysis

The total alkaloid content in the spikes was determined using the Soxhlet extraction method (Harbone, 1973).

Five grams of finely powdered dried samples was weighed in to the filter paper to hold the sample and the weight of sample with filter paper was recorded. The sample packet was then dropped into the extraction tube of Soxhlet apparatus. The bottom of the extraction tube was attached to the previously weighed Soxhlet flask. 100 ml of methanol was used as solvent, which was poured through the sample into the flask. The top of the extraction tube was attached to the condenser. Extraction of the sample was carried out in water bath maintained at 80^0C till the solvent in the extraction tube turned colourless. The temperature of water bath was regulated, so that the solvent volatilized, condensed and dropped continuously upon the sample without any appreciable loss. At the end of extraction period, ie., when the previously colourless solvent in the flask turned dark coloured and solvent in the extraction tube turned colourless, the sample packet was removed from the extractor and most of the solvent was distilled off by allowing it to collect in the Soxhlet tube. The Soxhlet flask was dismantled and allowed to cool. The solvent was evaporated on water bath. The Soxhlet flask along with residue was weighed. The residue left in Soxhlet flask after complete evaporation of the solvent was weighed to get the total alkaloid extracted.

$$\text{The alkaloid content (g)} = \text{Weight of soxhlet flask along with residue (g)} - \text{Weight of empty soxhlet flask (g)}$$

$$\text{Total alkaloid content (\%)} = \frac{\text{Weight of residue in grams}}{\text{Weight dried sample used for extraction}} \times 100$$

3.10 Economics

3.10.1 Cost of cultivation

The prices in rupees of the input that were prevailing at the time of their use were considering for working out cost of cultivation.

3.10.2 Gross returns

Gross returns per hectare was calculated by taking into consideration the prices of the products that prevailing in the market.

3.10.3. Net returns

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

3.10.4 Benefit Cost Ratio (BCR)

Benefit cost ratio was calculated as follows

$$BCR = \frac{\text{Gross Income}}{\text{Total Expenditure}}$$

3.11 Statistical analysis

The procedure outlined under SAS package was followed for the conduct of statistical analysis.

RESULTS

4. RESULTS

An investigation entitled, "Precision farming techniques in long pepper (*Piper longum* Linn.) under protected cultivation" was carried out at the Instructional Farm attached to the College of Agriculture, Padannakkad to develop cost effective agro techniques for improving the quality attributes, productivity and profitability of long pepper under protected cultivation and precision farming systems. The results obtained from the study are summarized in the following sections.

4.1.1 Vine length

Data on vine length as influenced by precision farming techniques under protected cultivation at 7, 8, 9, 10, 11 and 12 MAP are depicted in Table 5.

Vine length at all stages of growth except at 12 MAP was found to be significantly influenced by treatments. T5 on par with T4; T4 on par with T6, T_5 and T1; T5 on par with T4 and T1; T4 on par with T3; and T4 on par with T5 registered significantly higher values of vine length at 7, 8, 9, 10 and 11 MAP respectively. The treatments had no significant effect on vine length at 12 MAP. However the highest vine length of 272 cm was recorded by treatment T6 which was 0.73 per cent higher over the control, T14.

4.1.2 Total number of leaves

Total number of leaves as influenced by treatment effects at 7, 8, 9, 10, 11 and 12 MAP are presented in Table 6.

The treatments exerted significant effects on the total number of leaves at all stages of growth. T5 on par with T6, T7, and T4; T1 on par with T13; T5 on par with T4, T3, T11, and T13; T1 on par with T5, T3 and T2; and T1 on par with T5, T4 and T2 registered highest total number of leaves at 7, 8, 9, 10, 11 and 12 MAP.

Table 5. Vine length (cm) as influenced by precision farming techniques under protected cultivation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
T_1	37.75	71.67	135.61	151.25	192.27	270.15
T_2	36.95	71.55	134.85	150.40	192.15	270.70
T_3	36.76	71.45	135.55	152.15	192.30	271.15
T_4	38.55	72.10	136.05	152.75	192.60	271.45
T_5	39.40	71.75	137.26	150.73	192.55	271.65
T_6	37.50	71.80	134.97	151.14	192.48	272.00
T_7	37.25	70.95	134.40	151.66	191.88	270.95
T_8	36.12	70.77	134.25	151.02	191.66	271.15
T_9	35.23	70.62	134.50	150.11	190.73	271.19
T_{10}	33.95	70.62	132.70	150.02	190.62	271.07
T_{11}	33.80	70.06	133.33	150.12	190.41	271.02
T_{12}	32.25	70.32	133.84	150.05	190.13	271.04
T_{13}	31.00	70.24	132.22	149.41	190.05	271.03
T_{14}	29.50	69.97	131.02	149.00	190.00	270.78
SE	0.53	0.45	0.76	0.463	0.431	0.47
CD (0.05)	1.16	0.98	1.64	1.000	0.932	NS

MAP – Months After Planting

Table 6. Number of leaves as influenced by precision farming techniques under Protected cultivation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
T_1	16.82	33.30	59.90	69.61	80.74	119.82
T_2	17.09	31.80	60.07	67.73	79.72	119.15
T_3	16.18	31.40	60.87	68.62	80.02	117.67
T_4	18.10	31.03	61.05	67.39	79.32	119.28
T_5	18.77	30.95	61.92	65.84	80.30	119.73
T_6	18.54	30.72	59.27	65.65	79.20	114.95
T_7	18.11	30.74	59.13	67.25	78.78	112.43
T_8	17.95	31.10	59.84	63.71	77.75	111.45
T_9	16.69	30.15	59.15	64.28	79.12	113.65
T_{10}	15.92	30.91	58.78	65.14	79.11	111.27
T_{11}	16.07	30.74	60.80	65.93	78.75	111.27
T_{12}	15.14	31.67	60.28	65.66	76.64	109.40
T_{13}	15.14	32.15	60.62	63.51	78.10	108.76
T_{14}	14.29	29.79	59.78	62.89	76.49	107.14
SE	0.35	0.68	0.69	0.97	0.47	0.90
CD (0.05)	0.77	1.48	1.49	2.09	1.02	1.95

MAP – Months After Planting

respectively. The treatment T1 recorded the highest leaf number (119.8) and the per cent increase over control was 10.58.

4.1.3 Number of branches

Effects of treatment on number of branches recorded at 7, 8, 9, 10, 11, 12 MAP are depicted in Table 7.

Branching in long pepper was found to be significantly influenced by treatment effects only during early stages of growth ie, at 7 and 8 MAP. T5 at both stages registered highest number of branches i.e. at 7 and 8 MAP. T5 was on par with T14, T10, T7, T12 and T9 at 7 MAP and at 8 MAP it was on par with T12 and T14. Though not significant T7 exerted highest number of branches (4.6) at 12 MAP.

4.1.4 Root number

Effects of treatment on root number at 7, 8, 9, 10, 11 and 12 MAP are furnished in Table 8.

The effect of protected cultivation and precision farming techniques was not consistent in influencing root number. It resulted in significant effect on root number at 7 and 10 MAP. T7 on par with T3, T10, T13, T8, T5, and T9; and T9 0n par with T10, T13, T2, T11 and T12 recorded the greatest number of roots at 7 and 10 MAP. Though not significant T9 at 12MAP recorded the highest root number (53.67).

4.1.5 Root length

Treatment effects on root length at 7, 8, 9, 10, 11 and 12 MAP are furnished in Table 9.

Table 7. Number of branches as influenced by precision farming techniques under protected cultivation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
T_1	1.50	2.00	3.00	3.12	3.62	4.00
T_2	1.00	1.75	2.12	2.62	3.35	3.75
T_3	1.62	1.62	3.00	3.12	3.75	4.25
T_4	1.00	1.00	2.12	3.75	3.75	4.25
T_5	2.12	2.87	2.66	3.25	3.89	4.12
T_6	1.12	1.75	2.99	3.25	3.5	3.87
T_7	1.87	2.12	2.62	3.12	4.12	4.62
T_8	1.25	1.55	2.62	3.37	4.00	4.50
T_9	1.75	1.87	2.85	2.87	3.75	4.12
T_{10}	1.92	2.18	2.75	3.00	3.62	4.00
T_{11}	1.37	2.12	2.37	2.87	3.35	3.78
T_{12}	1.75	2.25	3.00	3.12	3.75	4.00
T_{13}	1.50	1.87	2.62	2.87	3.25	3.62
T_{14}	2.00	2.25	2.62	2.62	3.00	3.37
SE	0.19	0.31	0.41	0.27	0.37	0.42
CD (0.05)	0.42	0.68	NS	NS	NS	NS

MAP – Months After Planting

Table 8. Root number as influenced by precision farming technique under protected cultivation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
T_1	9.05	19.15	28.08	35.20	44.44	52.48
T_2	8.80	19.15	28.00	37.35	43.11	52.02
T_3	9.75	18.60	28.70	36.10	43.80	47.79
T_4	8.05	19.35	27.20	36.05	44.74	51.50
T_5	9.35	19.15	28.40	36.73	44.78	50.42
T_6	8.80	19.25	25.40	36.01	43.02	50.92
T_7	9.80	18.25	27.29	36.89	46.09	52.51
T_8	9.45	19.43	27.24	36.83	44.56	49.97
T_9	9.00	18.90	26.92	38.11	46.96	53.67
T_{10}	9.50	18.80	27.95	37.74	43.93	50.50
T_{11}	9.20	18.90	27.20	37.095	44.64	49.92
T_{12}	9.25	18.42	27.77	36.99	42.42	48.94
T_{13}	9.45	18.52	26.88	37.73	44.963	52.72
T_{14}	9.15	18.60	26.77	36.72	45.60	48.21
SE	0.252	0.460	0.94	0.534	1.51	2.17
CD (0.05)	0.545	NS	NS	1.15	NS	NS

MAP – Months After Planting

Table 9. Root length (cm) as influenced by precision farming technique under protected cultivation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
T_1	10.25	16.95	18.72	22.92	29.48	28.58
T_2	9.85	16.12	19.80	20.75	28.50	27.44
T_3	9.95	15.60	20.25	23.04	29.35	28.52
T_4	10.1	15.10	21.62	24.55	30.17	30.75
T_5	11.35	17.10	23.00	30.40	31.95	34.40
T_6	11.55	17.95	23.30	25.37	28.85	31.62
T_7	10.95	18.25	23.00	22.43	29.17	28.67
T_8	11.15	17.85	21.56	25.00	29.63	28.07
T_9	11.15	17.32	21.00	21.40	28.65	25.68
T_{10}	9.70	17.00	19.50	19.65	27.75	27.80
T_{11}	9.70	16.95	19.10	19.50	26.95	26.00
T_{12}	9.50	16.85	18.85	17.50	27.55	24.95
T_{13}	9.50	16.75	18.75	20.00	27.68	23.30
T_{14}	9.30	16.05	18.30	18.40	26.90	22.27
SE	0.15	0.15	0.69	1.20	0.71	0.71
CD (0.05)	0.34	0.33	1.50	2.59	1.55	1.55

MAP – Months After Planting

The effect of treatments on root length was spectacular at all stages of growth. T6 on par with T5 at 7 MAP; T7 on par with T6 at 8 MAP; T6 on par with T5 and T7 at 9 MAP; T5 at 10 and 11 MAP; and T4 on par with T3 at 12 MAP recorded the highest root length. T4 registered 35.26 per cent increase in root length compared to control.

4.1.6 Root spread

Mean data on root spread due to treatments effects at 7, 8, 9, 10, 11 and 12 MAP are given in Table 10.

The effect of treatments on root spread was not consistent at all stages of growth. Significant effect of treatments was evident only at 9, 10 and 11 MAP. T5 at 9 and 10 MAP; and T8 on par with T5 and T7 at 11 MAP were found to register higher root spread. At 7, 8, and 12 MAP also, the effect of treatment was significant on root spread. However T1 registered highest root spread of 30.30 cm at 12 MAP which was 17.01 per cent higher compared to control.

4.1.7 Root weight

Both fresh and dry weight of roots due to treatment effects at 7, 8, 9, 10, 11 and 12 MAP are furnished in Tables 11 and 12.

Significant influence of treatments on root fresh weight was observed at 9 and 12 MAP only. T2 on par with T7, T10 and T11 at 9 MAP; and T3 on par with T4, T5, and T10 at 12 MAP were found superior in influencing root fresh weight. At 12 MAP the per cent increase in root fresh weight in T3 was 11.60 per cent compared to the control.

The significant influence of treatments on root dry weight was evident only at 12 MAP. At 12 MAP, T4 on par with T5, T3, T10, and T6 recorded the highest root dry weight which was 19.75 per cent higher compared to control.

4.2 Leaf pigments

The mean data on the effect of precision farming techniques under protected cultivation on chlorophyll a, chlorophyll b and carotenoids are furnishing Table 13.

Leaf chlorophyll a ranged from 0.6-2.3 mg g^{-1} fresh leaf. The treatment T5 recorded the highest chlorophyll a content of 2.38 mg g^{-1} fresh leaves which was on par with T7, T1, T6, T8, T2, T3 and T9 compared to the control treatment T14. The treatment T5 recorded 73.5 per cent increase in chlorophyll a content.

The trend was almost similar with respect to chlorophyll b as well. Its content ranged from 0.08-0.29 mg g^{-1} fresh leaf and the highest value was recorded by the treatment T5 which was on par with T1, T7, T8, T6, T9 and T3. T5 recorded a significant increase of 72.41 per cent compared to T14.

Carotenoids also showed significant variation with respect to treatment effects and its content ranged from 5.9-21.9 mg g^{-1} fresh leaf. T5 recorded 21.91 mg g^{-1} fresh leaf which was 72.7 per cent higher compared to control.

4.2.1 Relative leaf water content

Data on relative leaf water content as influenced by precision farming techniques under protected cultivation are furnished in Table 13

Relative leaf water content was found to be significantly influence by treatment effects at 12 MAP. The treatment T6 which was found to be on par with T5, T8, and T2 recorded the highest relative leaf water content (86.05 %) which 39.73 per cent higher compared to control.

Table 10. Root spread (cm) as influenced by precision farming techniques under protected cultivation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
T_1	9.05	14.55	17.28	19.07	21.46	30.30
T_2	8.05	9.44	13.21	14.47	21.14	29.17
T_3	9.65	10.77	13.32	18.13	19.69	27.75
T_4	9.55	11.77	14.23	19.97	21.70	28.81
T_5	12.00	14.51	18.99	22.70	22.80	29.75
T_6	12.02	13.64	16.09	19.28	21.37	29.40
T_7	12.00	15.96	16.92	21.02	22.35	26.80
T_8	10.00	13.42	15.78	18.78	23.00	26.72
T_9	9.72	10.73	15.10	17.85	20.16	27.48
T_{10}	10.45	12.72	15.05	18.50	20.00	26.66
T_{11}	9.85	12.11	15.12	17.22	19.61	27.82
T_{12}	9.00	11.87	13.55	17.63	19.44	27.15
T_{13}	8.01	9.73	11.60	14.73	18.43	28.23
T_{14}	7.45	9.29	11.10	13.35	18.41	25.15
SE	1.49	0.56	0.43	0.53	0.38	1.30
CD (0.05)	NS	NS	0.935	1.159	0.823	NS

MAP – Months After Planting

Table 11. Root fresh weight (g $plant^{-1}$) as influenced by precision farming techniques under protected cultivation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
T_1	1.00	2.00	3.10	7.37	10.25	15.12
T_2	0.75	3.50	6.09	7.55	10.12	15.15
T_3	1.00	3.25	3.85	6.99	10.23	16.29
T_4	1.50	3.50	4.05	7.44	10.75	16.17
T_5	1.75	4.36	5.23	7.98	11.16	15.97
T_6	1.50	2.95	4.35	8.04	10.02	15.23
T_7	1.50	3.50	5.25	8.10	10.63	15.07
T_8	1.00	3.00	4.50	8.83	11.14	15.07
T_9	0.75	4.00	4.35	8.87	10.78	14.95
T_{10}	1.00	4.00	4.84	7.83	10.67	15.51
T_{11}	1.75	3.00	4.95	7.58	9.92	15.10
T_{12}	0.75	3.25	4.20	7.16	9.94	14.99
T_{13}	0.879	2.95	3.90	7.44	10.10	14.45
T_{14}	1.00	1.95	3.45	7.02	9.28	14.40
SE	0.59	1.48	0.72	0.79	0.64	0.43
CD (0.05)	NS	NS	1.57	NS	NS	0.93

MAP – Months After Planting

Table 12. Root dry weight (g $plant^{-1}$) as influenced by precision farming techniques under protected cultivation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
T_1	0.12	0.20	0.57	1.82	3.15	5.35
T_2	0.53	0.52	0.67	2.12	3.35	5.33
T_3	0.07	0.92	1.02	1.76	3.23	5.74
T_4	0.29	0.56	0.41	1.895	3.37	6.10
T_5	0.57	0.83	1.02	1.99	3.18	5.93
T_6	0.71	0.27	0.78	2.08	3.09	5.55
T_7	0.42	0.65	0.50	2.14	3.33	5.11
T_8	0.07	0.50	0.57	2.58	3.59	5.19
T_9	0.21	0.27	0.57	2.38	3.33	5.16
T_{10}	0.22	0.57	0.55	1.99	3.59	5.61
T_{11}	0.38	0.30	0.60	2.00	3.00	5.15
T_{12}	0.55	0.69	0.42	1.82	3.13	5.14
T_{13}	0.16	0.29	0.38	1.94	3.26	5.28
T_{14}	0.20	0.31	0.56	1.77	2.92	4.89
SE	0.35	0.32	0.28	0.25	0.25	0.30
CD (0.05)	NS	NS	NS	NS	NS	0.65

MAP – Months After Planting

Table 13. Leaf pigments, chlorophyll, carotenoids and relative leaf water content as influenced by precision farming techniques under protected cultivation

Treatments	Chlorophyll A (mg g^{-1})	Chlorophyll B (mg g^{-1})	Carotenoids (mg g^{-1})	SCMR	RWC (%)
T_1	2.02	0.28	20.54	51.02	70.15
T_2	1.90	0.19	14.44	43.74	75.82
T_3	1.89	0.24	18.18	49.15	74.20
T_4	1.43	0.19	14.40	41.92	73.45
T_5	2.38	0.29	21.91	56.89	83.20
T_6	2.00	0.25	18.84	54.30	86.85
T_7	2.32	0.28	20.69	51.09	71.25
T_8	1.96	0.26	19.05	49.53	76.45
T_9	1.84	0.24	17.74	42.75	72.98
T_{10}	1.33	0.14	10.58	40.22	69.46
T_{11}	1.28	0.17	13.06	36.25	62.63
T_{12}	1.27	0.11	9.73	36.75	67.72
T_{13}	1.28	0.11	8.82	36.45	63.75
T_{14}	0.63	0.08	5.98	32.96	51.63
SE	0.28	0.04	3.08	3.68	5.26
CD (0.05)	0.62	0.09	6.66	7.95	11.37

MAP – Months After Planting

4.2.2 PAR and Total solar radiation

Photo synthetically active radiation and total solar radiation as influenced by precision farming techniques under protected cultivation are presented in Table 14.

Significantly influence of treatments was evident on PAR observed at 12 MAP. The control treatment T14 on par with T10, T13, T12, and T11 recorded the higher value which ranged from 803-142 Watts m^{-2}.

Total solar radiation recorded at 12^{0}clock ranged from 329-1903 KW m^{-2}. The maximum value was recorded by the treatment T13 and it was on par with T11, T14, T12.

Total solar radiation recorded at 2^{0}clock ranged from 252-1270 KW m^{-2}. The maximum value was recorded by the treatment T10 and it was significantly different from all other treatments.

4.3 Spike number per plant

Spike number per plant as influenced by precision farming techniques under protected cultivation at 7, 8, 9, 10, 11 and 12 MAP are furnished in Table 15.

Spike number (7, 8, 9, 10, 11 and 12 MAP) per plant was found to be significantly influenced by treatments effects at all stages of growth. At 7 MAP the treatment T1 on par with T5, T11 and T10 recorded the highest spike number and it was 54.16 per cent higher compared to control.

Table 14. Total solar radiation (W m^{-2}) and photo synthetically active radiation (KW m^{-2}) as influenced by precision farming techniques under protected cultivation

Treatments	12^o Clock	2^o Clock	PAR
T_1	519.00	260.00	196.00
T_2	580.00	287.00	230.00
T_3	515.00	306.00	188.50
T_4	627.50	252.50	246.50
T_5	467.50	252.00	142.00
T_6	329.50	329.50	167.00
T_7	429.50	320.00	191.50
T_8	525.00	335.50	199.00
T_9	444.50	354.00	168.00
T_{10}	1379.00	1270.50	790.00
T_{11}	1883.50	697.00	747.50
T_{12}	1683.00	591.50	765.00
T_{13}	1903.00	955.00	786.00
T_{14}	1869.00	718.00	803.00
SE	210.78	137.59	36.29
CD (0.05)	455.38	297.25	79.70

Table 15. Spike number as influenced by precision farming techniques under protected cultivation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP	Total
T_1	3.00	3.50	4.99	11.05	22.90	33.85	79.29
T_2	2.05	4.00	4.61	12.15	21.05	29.00	72.86
T_3	1.80	2.50	5.25	15.40	24.00	29.65	78.60
T_4	1.75	2.12	4.83	17.50	26.30	32.10	84.60
T_5	2.75	4.625	6.77	19.65	29.85	38.75	102.40
T_6	1.75	3.45	3.68	13.31	30.30	34.50	87.00
T_7	2.00	2.50	3.89	15.05	19.95	26.95	70.34
T_8	1.37	2.75	4.17	13.05	18.05	26.15	65.55
T_9	1.87	2.87	5.20	11.69	19.00	23.70	64.35
T_{10}	2.50	2.87	4.78	12.51	14.65	20.55	57.87
T_{11}	2.62	3.30	4.12	11.73	14.25	22.25	58.35
T_{12}	1.87	4.37	5.12	11.65	14.15	21.00	58.17
T_{13}	1.62	2.60	3.62	10.70	10.31	16.80	45.66
T_{14}	1.87	1.87	2.75	7.85	9.60	13.30	37.25
SE	0.69	0.68	1.25	4.77	5.64	7.50	14.13
CD (0.05)	0.103	0.315	0.582	2.20	2.61	3.47	6.54

MAP – Months After Planting

At 7 MAP the treatment T1 on par with T5, T11, and T10 recorded the highest spike number which was 37.66 per cent higher compared to control. However, the trend was slightly different at all other stages. The treatment T5 recorded the highest spike number at 8, 9, 10 and 12 MAP where as T6 was found to be superior at 11 MAP. T14 registered the lowest value at all stages of growth. T5 on par with T12 and T2 at 8 MAP registered 59.52 per cent higher spike number compared to control. T5 recorded 6.78 number of spikes at 9 MAP, which was 59.43 per cent higher compared to control. The treatment showed significant superiority when compared to all other treatments. The same treatment T5, again showed significant superiority at 10 MAP but was on par with T4, T3, T7 and recorded 60.05 per cent higher spike number compared to control.

T6 on par with T5 and T4 showed significant superiority at 11 MAP compared to all other treatments and increase in spike number was the tune of 68.31 per cent compared to control T14. Similar to treatment effects at 8, 9, 10 MAP, T5 again showed highest spike number at 12 MAP which was on par with T6 and T11 and 65.67per cent higher compared to control

The highest total spike number was recorded by the treatment T_5 and it was found to be on par with T_6. The percent increase in spike number in treatment T_5 was 63.69 per cent over the control, $T_{14.}$

4.3.1 Spike yield

Spike yield (kg ha^{-1}) plant both fresh and dry due to treatment effects at 7, 8, 9, 10, 11 and 12 MAP are furnished in Tables 16 and 17.

Protected cultivation and precision farming techniques significantly influenced fresh spike yield at all stages of harvest. T7 at 6 MAP and T5 at all other stages of harvest i.e. 8, 10 & 12 MAP showed the highest values. At 6 MAP T7 on par with T5, T6 and T8 registered highest value which was 38.30 per cent higher compared to T14. The trend was slightly different at all the stages of harvest. At 8 MAP, T5 was significantly different from all other treatments and increase in yield was 50.83 per cent over the control. Though T_5 showed higher yield at 10 MAP it was on par with T7 and T8 and the percent increase in yield recorded was tune of 56.58 per cent over control. T5 which was on par with T7, T6, T1 and T8 at 12 MAP showed significantly higher yield and the increase was 48.1 per cent compared to control.

Similar to fresh spike yield the dry spikes yield per hectare was also found to be significantly influenced by protected cultivation and precision farming techniques and the trend was exactly similar to fresh spike production.

4.3.2 Total Dry matter production

Mean total fresh and dry matter production as influenced by precision farming under protected cultivation are furnished in Tables 18 and 19.

Protected cultivation and precision farming technique significantly influenced total biomass (fresh) production at all stages of growth from 7 - 12 MAP except at 8 MAP. In general, the treatment effects were inconsistent at various stages of growth. T5 on par with T4 and T12 at 7 MAP, T5 at 9 MAP, T6 on par with T5 at 10 MAP, T5 on par with T3, T7, T6, T1, T8 and T4 at 12 MAP recorded significantly higher biomass production. The treatment effects were inconsistent at various stages of growth. At 12 MAP, the highest biomass production of 54.30 gm $plant^{-1}$ was recorded by T5 and it was 27.8 per cent higher compared to control.

Similar to total biomass (fresh) production, total dry matter production was also found to be significantly influenced by protected cultivation and precision farming techniques and the trend was exactly similar to total biomass production.

Table 16. Fresh spike yield (kg ha^{-1}) as influenced by precision farming techniques under protected cultivation

Treatments	6MAP	8MAP	10MAP	12MAP	Total
T_1	74.95	153.80	288.25	387.10	904.10
T_2	64.15	130.60	255.8	369.35	819.90
T_3	64.20	125.85	257.65	354.85	802.55
T_4	61.20	124.15	257.90	349.30	792.55
T_5	95.45	179.80	333.55	414.42	1023.22
T_6	92.95	160.25	309.70	393.65	956.55
T_7	98.95	170.42	324.40	401.95	995.72
T_8	92.90	148.95	314.65	385.05	941.55
T_9	87.72	129.35	240.15	330.40	787.62
T_{10}	77.65	115.45	215.60	311.19	719.89
T_{11}	76.65	113.40	218.80	302.80	711.65
T_{12}	73.10	110.95	209.65	295.00	688.70
T_{13}	67.10	102.45	186.95	276.60	633.10
T_{14}	61.05	88.40	144.80	215.00	509.25
SE	3.21	6.41	9.44	15.39	27.55
CD (0.05)	6.94	13.86	20.40	33.27	59.514

MAP – Months After Planting

Table 17. Dry spike yield (kg ha^{-1}) as influenced by precision farming techniques under protected cultivation

Treatments	6 MAP	8 MAP	10 MAP	12 MAP	Total
T_1	35.44	79.23	145.78	202.88	463.33
T_2	30.99	68.34	131.90	189.70	420.93
T_3	31.34	66.435	132.83	181.44	412.04
T_4	29.98	64.635	130.95	181.09	406.65
T_5	51.63	91.90	169.28	211.21	524.03
T_6	50.44	82.70	157.86	201.83	492.83
T_7	51.86	87.71	164.70	202.51	506.78
T_8	48.72	77.52	160.33	195.54	482.12
T_9	45.87	67.23	124.09	173.73	410.92
T_{10}	41.87	61.24	111.30	160.09	374.51
T_{11}	40.44	60.98	113.55	156.38	371.36
T_{12}	38.53	59.48	111.78	152.29	362.10
T_{13}	36.08	53.23	102.68	141.86	333.86
T_{14}	32.73	48.65	77.40	113.90	272.69
SE	1.79	2.94	4.55	7.39	12.70
CD (0.05)	3.87	6.36	9.84	15.97	27.64

MAP- Months After Planting

Table 18. Total biomass production (fresh) g plant^{-1} weight as influenced by precision farming techniques under protected cultivation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
T_1	13.90	35.00	48.00	70.75	103.10	155.74
T_2	18.00	44.00	54.00	74.68	95.65	150.30
T_3	13.23	47.00	56.15	77.72	100.50	154.30
T_4	24.85	39.50	64.50	74.75	104.05	148.60
T_5	25.75	49.00	66.50	80.31	107.15	153.90
T_6	21.50	40.50	59.50	81.93	99.30	153.60
T_7	25.30	41.00	48.35	75.66	96.15	139.95
T_8	19.85	45.00	50.20	75.66	96.90	131.85
T_9	20.00	46.00	51.65	79.25	93.62	132.59
T_{10}	17.00	40.00	45.00	75.12	92.41	128.65
T_{11}	19.00	39.50	44.12	73.18	88.00	122.18
T_{12}	25.00	44.50	49.50	72.79	88.65	123.77
T_{13}	20.00	30.00	38.30	74.04	89.80	124.13
T_{14}	20.10	24.35	30.67	67.30	88.15	120.47
SE	3.79	3.98	4.68	2.02	3.06	5.56
CD (5 %)	NS	8.60	10.12	4.38	6.62	12.01

MAP- Months After Planting

Table 19. Total biomass (dry) production g plant^{-1} as influenced by precision farming techniques under protected cultivation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
T_1	5.98	11.80	16.73	22.95	31.99	53.07
T_2	6.50	22.14	18.92	24.24	31.37	52.39
T_3	4.98	15.09	19.01	24.85	33.53	54.30
T_4	8.85	13.88	22.55	23.58	31.87	51.42
T_5	9.33	16.66	25.42	27.98	34.73	54.10
T_6	7.77	13.86	20.07	28.17	32.90	53.12
T_7	9.16	14.67	16.68	24.11	33.03	47.63
T_8	6.14	17.14	17.02	24.05	31.89	45.91
T_9	6.20	18.56	17.16	22.65	31.15	45.63
T_{10}	5.45	13.92	16.01	22.97	30.09	42.87
T_{11}	6.24	13.57	15.03	21.64	28.48	41.45
T_{12}	8.75	18.46	17.05	20.58	29.80	42.25
T_{13}	6.87	9.90	13.10	22.60	28.75	42.20
T_{14}	6.15	8.84	11.10	19.40	26.95	39.19
SE	0.37	0.47	0.42	1.21	1.37	2.19
CD (0.05)	0.81	NS	0.91	2.62	2.90	4.73

4.3.4 Yield and Quality

Total production of alkaloid and spikes per hectare as influenced by precision farming techniques under protected cultivation are presented in Table 20.

Total spike production ranged from 272-524 kg ha-1. The highest dry spike yield of 524 kg per hectare was recorded by the treatment T5 and it was found to be on par with T7. The increase in spike production in T5 was 47.96 per cent higher over the control.

The alkaloid content ranged from 5.12 to 6.05 per cent. Total alkaloid production per hectare was found to be significantly influenced by treatment effects and it varied from 15.58 to 29.58 kg ha^{-1}. The highest alkaloid production of 29.5 kg ha^{-1} was recorded by treatment T_5 which 47.32 per cent higher compared to the control. T_5 was found to be on par with T_7, T_6, T8, and $T_{1.}$

4.4 Uptake studies

Nutrient uptake in leaf and spike as influenced by precision farming techniques under protected cultivation are presented in Tables 21 and 22.

Uptake of nitrogen and potassium was found to be significantly influenced by treatment effects. However, phosphorus uptake was unaffected by protected cultivation and precision farming techniques.

T_5 on par with T_7, T_3, T_4, T_6 and T_2 recorded the highest uptake of N which was found to be 42.08 % higher compared to the control. Though phosphorus uptake was unaffected by treatment effects, T_7 recorded the highest uptake of 8.90 kg ha^{-1} which was 43.53 per cent higher compared to the control, T14. With respect to potassium uptake, T_1 and T_3 were on par and increase recorded by T_1 over the control T_{14} was 31 per cent.

Table 20: Yield and quality as influenced by precision farming techniques under protected cultivation

Treatments	Total dry spike yield (kg ha^{-1})	Alkaloid %	Total alkaloid kg/ha
T_1	463.33	5.90	27.32
T_2	420.93	5.90	24.77
T_3	412.04	6.05	24.90
T_4	406.65	5.77	23.45
T_5	524.03	5.65	29.57
T_6	492.83	5.65	27.90
T_7	506.78	5.76	29.20
T_8	482.12	5.70	27.45
T_9	410.92	5.57	22.87
T_{10}	374.51	5.50	20.61
T_{11}	371.36	5.98	22.20
T_{12}	362.10	5.59	20.25
T_{13}	333.86	5.69	19.01
T_{14}	272.69	5.71	15.58
SE	12.70	O.46	1.184
CD (0.05)	27.69	NS	2.55

N and K accretion in spikes were found to be significantly influenced by treatment effects. T_5 recorded the highest uptake of 6.503 kg N ha^{-1}. Compared to the control, the per cent increase in nitrogen uptake of spike was 43.72 per cent. Though not significant, the highest phosphorus uptake was recorded by T_1 followed by T_5 and T_8. With respect to potassium uptake T_5 was found to be superior and was on par with T_7 and T_6. The per cent increase in K uptake over control $T_{14,}$ was 51.40.

4.5 Soil moisture

Mean data on moisture content of the soil before and after irrigation, seasonal consumptive use, mean daily cu, crop coefficient, crop water use efficiency, field water use efficiency and water productivity as influenced by precision farming techniques under protected cultivation are furnished in Table 23.

The treatments effects had significant influence on soil moisture content after irrigation and the values ranged from 18.85 - 20.85 per cent. The treatment T5 recorded the highest moisture content after irrigation and it was on par with T6, T8, T7, T13, T3, T12 and T9. The per cent increase in soil moisture in T5 was 11.03 compared to the control T14. However, soil moisture estimation prior to irrigation revealed no significant difference due to treatment effects.

Seasonal consumptive use and mean daily consumptive use also showed significant variation due to treatment effects. Except the two control treatments, T9 and T14; all the other 12 treatments where micro irrigation systems were installed were on par. The highest seasonal cu of 599.49 mm was recorded by T8 and it was 70.95 per cent higher compared to T14. The same treatment T8 recorded the highest mean daily cu of 1.64 mm which was 71.34 per cent compared to T14.

The two control treatments, T9 and T14, which received life saving irrigation showed higher crop water use efficiency and FWUE. The highest CWUE of 2284.96 g m^{-3} was recorded by the control treatment T9 which was

Table 21. Nutrient uptake in leaf as influenced by Precision farming techniques under protected cultivation.

Treatments	Total dry matter in leaf	N %	P %	K %	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}
T_1	1768.97	1.51	0.35	1.54	26.65	6.25	27.25
T_2	1746.30	1.55	0.35	1.32	27.19	6.18	23.02
T_3	1810.17	1.58	0.38	1.38	28.61	6.83	24.98
T_4	1714.17	1.67	0.35	1.30	28.55	6.01	22.22
T_5	1803.33	1.77	0.43	1.19	31.87	7.74	21.54
T_6	1770.67	1.60	0.40	1.34	28.39	7.08	23.69
T_7	1587.82	1.82	0.50	1.45	28.83	8.08	23.46
T_8	1530.50	1.72	0.51	1.39	26.40	7.80	21.33
T_9	1521.00	1.61	0.41	1.33	24.57	6.21	20.32
T_{10}	1429.17	1.60	0.4	1.45	22.86	5.70	20.75
T_{11}	1381.67	1.60	0.43	1.40	22.10	6.01	19.44
T_{12}	1408.50	1.56	0.41	1.43	22.03	5.84	19.92
T_{13}	1406.33	1.60	0.46	1.58	22.49	6.46	22.29
T_{14}	1306.50	1.41	0.35	1.39	18.46	4.56	18.18
SE	73.02	0.19	0.05	0.11	2.23	0.90	1.54
CD (0.05)	157.71	NS	NS	NS	4.82	NS	3.3

Table 22. Nutrient uptake in Spike as influenced by Precision farming techniques under protected cultivation.

Treatments	Total dry spike yield (kg ha^{-1})	N %	P %	K %	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}
T_1	463.33	1.25	0.35	1.36	5.78	1.62	6.29
T_2	420.93	1.30	0.28	1.37	5.49	1.19	5.77
T_3	412.04	1.20	0.26	1.32	4.95	1.07	5.46
T_4	406.65	1.35	0.25	1.31	5.48	1.01	5.32
T_5	524.03	1.25	0.29	1.34	6.53	1.54	7.02
T_6	492.83	1.15	0.25	1.36	5.67	1.22	6.70
T_7	506.78	1.25	0.23	1.35	6.32	1.16	6.85
T_8	482.12	1.15	0.31	1.33	5.54	1.49	6.40
T_9	410.92	1.15	0.29	1.31	4.73	1.18	5.37
T_{10}	374.51	1.27	0.27	1.40	4.75	1.01	5.25
T_{11}	371.36	1.35	0.31	1.36	4.98	1.17	5.04
T_{12}	362.10	1.25	0.32	1.35	4.28	1.15	4.88
T_{13}	333.86	1.30	0.29	1.25	4.33	0.96	4.17
T_{14}	272.69	1.35	0.29	1.25	3.67	0.79	3.41
SE	12.70	0.10	0.05	0.06	0.45	0.22	0.28
CD (0.05)	27.64	NS	NS	NS	0.97	NS	0.61

Table 23. Soil moisture as influenced by precision farming techniques under protected cultivation

Treatments	Soil moisture (%)		Seasonal Cu (mm)	Mean daily Cu (mm)	CWUE (g m^{-3})	KC	FWUE (gm^{-3})	Water Productivity (gm^{-3})
	After	Before						
T_1	19.65	15.10	506.49	1.38	915.57	0.67	8.00	1018.42
T_2	19.65	15.00	515.07	1.40	817.40	0.68	7.26	1001.53
T_3	20.00	14.99	490.62	1.33	846.05	0.65	7.11	1042.08
T_4	19.4	14.65	523.51	1.43	779.10	0.70	7.01	986.85
T_5	20.85	15.80	548.84	1.50	982.79	0.73	7.26	834.00
T_6	20.85	15.30	536.17	1.46	937.38	0.71	6.83	818.89
T_7	20.35	15.65	519.29	1.41	1012.33	0.69	7.02	734.34
T_8	20.45	14.80	599.49	1.64	812.26	0.79	6.68	707.82
T_9	19.8	14.45	179.99	0.48	2284.96	0.23	46.3	5722.35
T_{10}	19.05	14.60	498.18	1.36	755.73	0.66	6.44	819.94
T_{11}	19.00	14.10	531.95	1.45	698.58	0.70	6.38	792.68
T_{12}	19.85	14.35	553.05	1.51	661.01	0.74	6.22	808.08
T_{13}	20.10	14.20	565.72	1.54	590.13	0.75	5.74	807.01
T_{14}	18.85	14.05	174.36	0.47	1563.77	0.24	30.50	4860.49
SE	0.49	0.10	64.10	0.17	131.87	0.08	0.44	158.22
CD (0.05)	1.074	NS	138.64	0.37	284.85	0.18	0.96	341.77

Significantly different from all other treatments. The same treatment T9 also showed the highest FWUE and showed significant superiority over all other treatments.

All the treatments which received micro irrigation were on par in relation to water productivity. The control treatments T9 and T14 registered the highest water productivity of 572.44 g m^{-3} which differed significantly from all other treatments.

4.6 Economic analysis

Mean data on economic analysis of the system with respect to cost of cultivation, gross income, net income and B:C ratio as influenced by precision farming techniques under protected cultivation are summarized in Table 24.

The Gross income from long pepper cultivation showed significant variation due to treatment effects and it ranged from 1.91 lakh per ha to 3.7 lakh per ha. The treatment, T5 recorded the highest gross income of 3.7 lakh per ha which was on par with T7 and both the treatments differed significantly from all other treatments compared to the control treatment. T5 recorded 47.96 per cent increase in gross income.

With respect to net income the treatment T5 on par with T7 and T6 showed the highest values and differed significantly from all other treatments. The highest net income of Rs. 1.9 lakhs per hectare was registered by the treatment T5 which was 57.16 per cent higher compared to the control.

Significant variation in B : C ratio was observed with respect to treatment effects and it varied from 1.7-2.0. Similar to gross income and net income, the highest B : C ratio of 2.06 was registered by T5 and it was on par with T7, T6, T1, T5, T8 and T11. Compare to the control treatment the treatment T5 recorded 18.39 per cent increase in B : C : R.

Table 24. B:C ratio as influenced by precision farming techniques under protected cultivation

Treatments	Cost of cultivation (Rs ha^{-1})	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	B : C Ratio
T_1	162000	324335	162335	2.00
T_2	157000	294655	137655	1.87
T_3	159000	288432	129432	1.81
T_4	154000	284659	130659	1.84
T_5	173000	366821	188821	2.06
T_6	168000	344995	172995	2.00
T_7	17000	354750	179750	2.02
T_8	165000	337484	167484	1.98
T_9	150000	287473	147473	1.98
T_{10}	132000	262157	125157	1.91
T_{11}	127000	259952	127952	1.96
T_{12}	130000	253435	119435	1.89
T_{13}	125000	233702	104702	1.81
T_{14}	110000	190887	80886.5	1.73
SE		8983.40	8983.40	0.04
CD (0.05)		19404.20	19404.20	0.10

5. DISCUSSION

The results of the experiment presented in the previous chapter are discussed in the following paragraphs.

5.1 Growth characters

In general, planting in trenches filled with enriched growth medium + staking + fertigation through drip system along with growing of a second storey long pepper crop above the ground planted one in hanging pots with mist irrigation was found beneficial for improving growth characters, viz, vine length, total number of leaves and number of branches in long pepper intercropped in coconut gardens under protected cultivation compared to the two control treatments, viz planting in trenches filled with potting mixture + without staking + life saving irrigation under protected cultivation in the interspaces of coconut garden and planting in trenches filled with potting mixture + without staking + life saving irrigation under the partial shade of coconut trees (Table Nos. 5, 6,7 and ; Fig Nos. 3,4,5).

Vine length, number of branches and total number of leaves influence both the photosynthetic capacity and transpirational loss of water. The growth of a plant is influenced by the metabolic activities which require adequate amounts of nutrients and water. Integrated management of long pepper by incorporating enriched growth medium in the rhizosphere + staking + fertigation through drip system along with growing of a second storey long pepper crop above the ground planted one in hanging pots with mist irrigation is beneficial for maintaining optimum moisture-nutrient-oxygen regime in soils. Enriched growth medium (dry powdered cowdung, vermicompost, composted coir pith and bone meal) might have released sufficient quantities of nutrients for crop growth resulting in vigorous growth which reflected on growth characters. The three beneficial microorganisms, viz, Trichoderma, Azospirillum and Pseudomonas applied along with the above

A) 6 MAP

B) 8 MAP

C) 10 MAP

D) 12 MAP

Plate. 2 General view

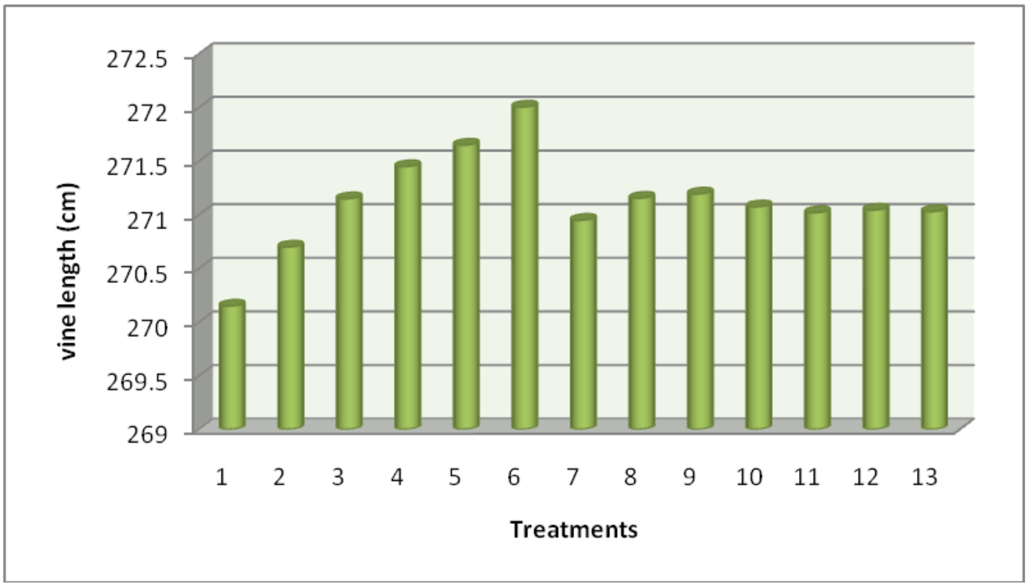

Fig.3. Vine length at 12 MAP as influenced by precision farming techniques Under protected cultivation

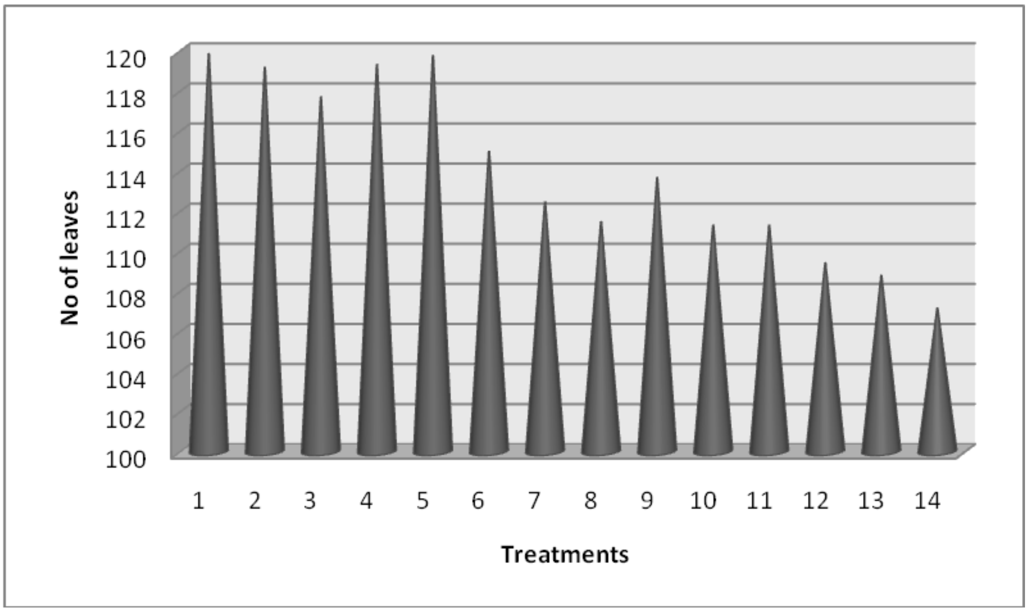

Fig. 4. Number of leaves at 12 MAP as influenced by farming techniques under protected cultivation

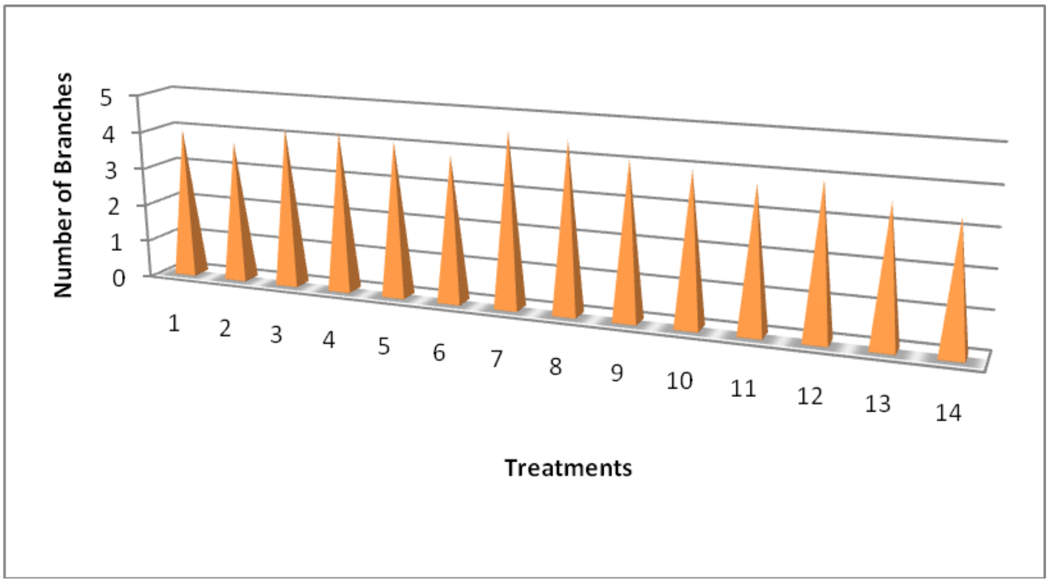

Fig. 5. Number of branches at 12 MAP as influenced by precision farming techniques under protected cultivation

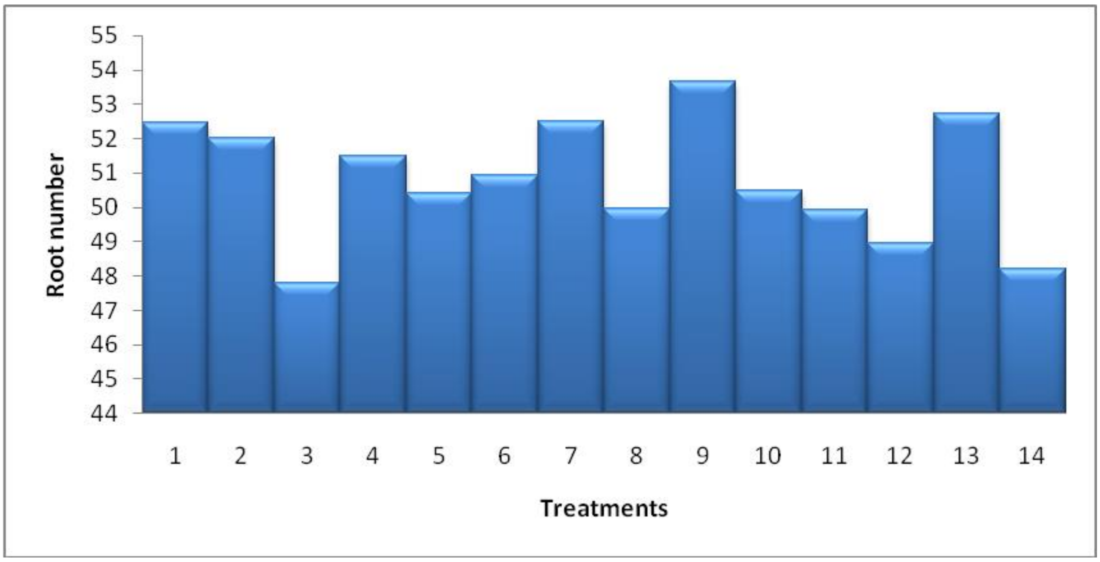

Fig.6. Root number at 12 MAP as influenced by precision farming techniques under protected cultivation

organic manure available in the rhizosphere were beneficial for disease suppression, biological nitrogen fixation and production of growth hormones for plant growth promotion respectively which might have contributed to luxuriant growth of long pepper. Rotational application of liquid organic manures, viz, vermiwash, panchagavya and jeevamritha through drip and mist ensured the availability of plant nutrients throughout the crop stages which might have consistently enhanced the growth of crop. Water was not a limiting factor for crop growth as it was ensured through drip system. Proper disposition of leaves also helped the plants to receive more sunlight which might have promoted profuse branching in staked plots. So there is better conservation and efficient utilization of irrigation water and nutrients due to treatment effects which might have resulted in better growth of long pepper.

Similar results due to sustained availability of nutrients by split application of fertilizers in betel vine have been reported by other workers (Maithi *et al.*, 1997 and Jahan, 1999). Foliar sprays with liquid organic manures exhibited their significance over control and exhibited enhanced growth and productivity. Vermiwash is very useful for foliar application to enhance the plant growth and yield as it is a collection of excretory products and mucus secretions of earthworm along with nutrients from the soil organic molecules (Ismail and Pramoth, 1995). Panchagavya is applied to safeguard the plant and soil microbes besides increasing crop productivity. Presence of growth regulating substances such as IAA, GA3, and cytokinin, essential plant nutrients in panchagavya promotes plant growth. Effective microorganisms predominantly lactic acid bacteria, certain beneficial biofertilizers and plant protection substances are detected in panchagavya (Pandian *et al*., 2000). The efficacy of vermiwash and cowdung on morpho-physiological parameters of soyabean (*Glycine max* L.) have been reported by Deotale, *et al*. (2008). Nutrients applied through foliar sprays might have accelerated the metabolic and physiological activity of the plant and put more growth by assimilating more amount of major nutrients and ultimately increased the leaf area plant^{-1} ((Deotale, *et al*. 2008).

Adequate supply of soil moisture can maintain optimum turgor potential which opens the stomatal aperture for gaseous exchange and leads to higher photosynthetic rate and ultimately increases plant growth characters and yield. This was confirmed in long pepper by Manjunath *et al*., (2007). The performance of drip fertigated crop was better in relation to plant height, leaf area index, crop growth rate, relative growth rate, leaf area duration, biomass, net assimilation rate and dry matter production (Jadav et al., 1995).

Considerable improvement in biometric characters like vine length, number of branches and number of leaves were observed under protected cultivation compared to control. Similar results were revealed by Etampawala et al., (2002). The shoot of *P.longum* grown under medium shade condition were significantly taller compared to those grown under low shade and deep shade. Under medium shade, plant produced significantly higher number of leaves compared to those grown under low and deep shade.

Reduction in plant height under life saving irrigation was due to reduced stem growth, cell elongation and reduced photosynthesis (Begg and Turner, 1976). The primary plant process affected by water stress is cell elongation due to reduction in turgor pressure. Cell expansion is also adversely affected due to reduced turgor pressure resulting in reduced plant height under water stress (Nath, 1993). Reduction in leaf number under life saving irrigation might be due to water stress inhibition of cell division and cell expansion for effectively conserving water by reducing transpiration because of limited water supply in the soil over a period of time. One of the mechanisms of water stress tolerance is to reduce the transpirational surface area which helps the plants to reduce the heat load on the leaves (Nath, 1993). Water stress induces senescence and early abscission which when combined with reduced primordial initiation result in reduced number of leaves per plant. Decrease in leaf number may be a mechanism of the species to reduce water loss in response to restricted water availability (Shubhra *et al*., 2004).

5.2 Root growth

The effect of protected cultivation and precision farming techniques was not consistent in influencing root number at various stages of growth. In general, more number of roots were formed when the plants were allowed to creep over the land surface which enabled the plant to strike roots at every node. This was more pronounced during the later stages of growth as all the branches were creeping. Compared to drip system, micro sprinkler system was congenial for promoting root number. Moisture distribution pattern in microsprinkler was different compared to drip system and the wetting front of the former wetted the entire soil surface unlike rhizosphere alone in the drip system (Table Nos, 8, 9, 10, 11, 12 and Fig Nos, 6, 7, 8).

In general, elongation of the roots of ground grown crop resulted when protected cultivation was practiced with a second storey of long pepper along with overhead mist fertigation. Rotational foliar application of liquid organic manures through mist system enriched the entire soil surface with readily assimilable forms of plant nutrients favouring elongation of roots. Similar to root elongation, the effect of treatments on root spread was also not consistent at all stages of growth. However, similar trends were observed with respect to root length and root spread indicating that the factors contributed to root elongation might have favoured root spread as well. Significant influence of treatment on root dry weight was evident only at 12 MAP. Long pepper grown under protected cultivation with microsprinkler system of irrigation but without staking produced the highest root dry weight. The reasons attributed for root elongation and root spread might have favoured root weight. The rooting medium physically supports the growing medium and supplies water, nutrients and oxygen to the root system. The better the medium, the better will be the development of healthy fibrous root system and better establishment and development. A proper blend of organic manures constituted an excellent medium for efficient root growth. The characteristics of the different components of the enriched growth medium are worth mentioning in this context. It has several advantages for root development.

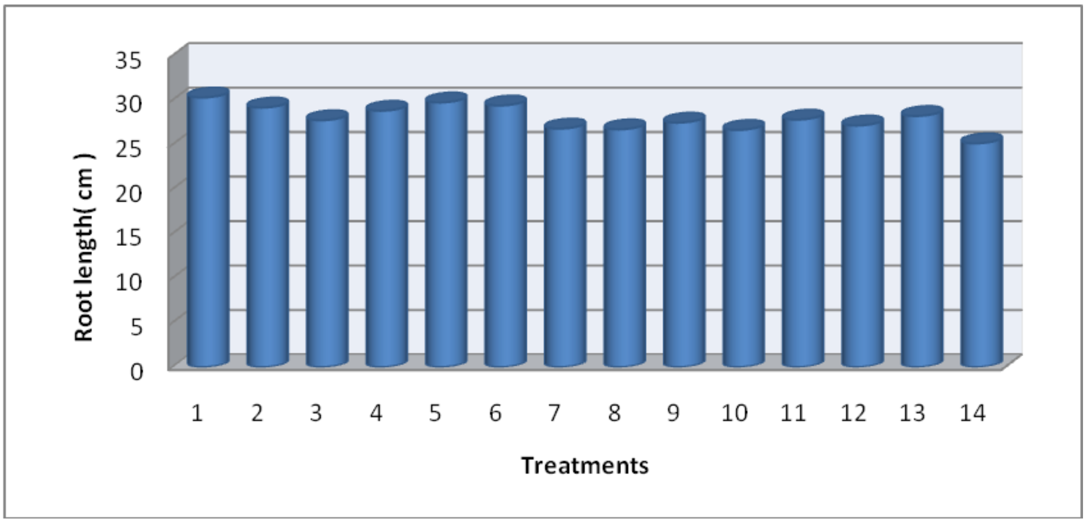

Fig. 7 Root length at 12 MAP as influenced by by precision farming technique under protected cultivation

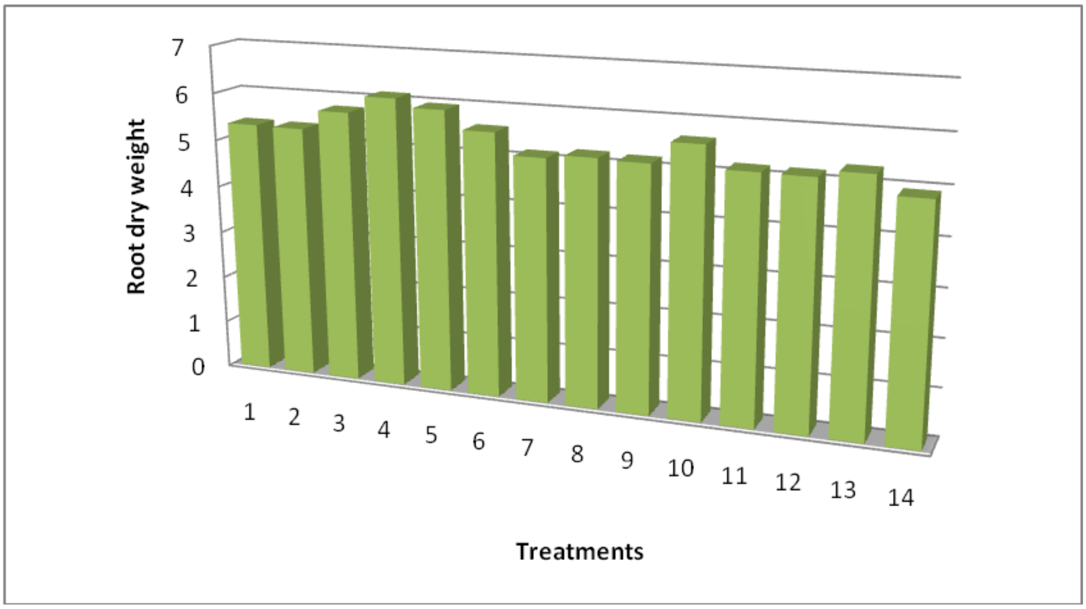

Fig. 8 Root dry weight as influenced by precision farming technique under protected cultivation

It contains significant quantities of available nutrients, beneficial micro organisms and biologically active metabolites particularly gibberellins, auxins, cytokinins and group B vitamins (KAU, 2001). Coir pith has high surface area, low bulk density, low thermal conductivity and high porosity. There are several reports about its suitability for rain water conservation (Joseph, 1995, Gopinathan, 1996, Salam et al., 1993 and Venkitaswamy and Khan, 2004).

5.3 Physiological parameters

Leaf chlorophyll a content ranged from 0.6-2.3 mg g^{-1} leaf. Carotenoids also showed significant variation with respect to treatment effects and it content ranged from 5.9-21.9 mg g^{-1} fresh leaf. In both cases, cultivation of long pepper in enriched growth medium with proper staking and fertigation through drip system and maintenance of a second storey crop with mist irrigation considerably improved leaf chlorophyll and carotenoids. In most cases, crop productivity is limited by availability of photosynthates and its utilization. Production of photosynthates depends on photosynthesis, which is regulated by the rate of light and dark reactions, availability of carbon dioxide, moisture and chloroplasts. All green coloured plant parts contain pigments, which absorb light and play important roles in photosynthesis and photodamage (Table No 13).

Relative leaf water content was found to be significantly influence by treatment effects and there was considerable improvement under protected situation compared to the control treatments. Relative leaf water content is a commonly used indicator for plant water status because it is easy to measure on various plant materials. The relationships between relative water content and water potential differ with species. Under stress conditions a species with higher relative water content is more drought resistant. Studies have shown that maximum relative water content is an useful criterion to differentiate between drought resistant and drought susceptible cultivars. A species with higher relative leaf water content at water potential of -1.5 MPa is more drought resistant.

The above results are in line with the findings of Leopold *et al*., (1981). The percentage of electrolyte leakage was the highest (less membrane integrity) under open field condition in Kohinoor and lowest under 35% shade in sweet pepper cultivar Indra. This was due to extremes of temperature in open field which increased the percentage of leakage in, followed with reduction in photosynthetic efficiency and respiration rate and accelerated senescence. The highest yield under shade might be due to reduced leakage percentage. Similar result was observed by Kavitha (2005) in tomato. The reduction in leaf relative water content under open field condition could be attributed to increased light intensity, transpiration rate, and reduced stomatal diffusive resistance. This is an accordance with findings of Dhindsa *et al*. (1981).

Reduction in leaf water content might be the reason for poor yield under open field condition. This is in conformity with the findings of Slayter (1995), who observed that reduction of relative leaf water content in plants by five per cent may lead to a reduction in photosynthetic efficiency by 40-60%.

Long pepper received more total solar radiation and photosynthetically active radiation when grown in the interspaces of coconut garden under unprotected condition compared to protected cultivation. The shade net used for protection had reduced the availability of both total solar radiation and photosynthetically active radiation under protected cultivation.

5.4 Spike number and spike yield per plant

Wide variation was observed with respect to spike number per plant at all harvests and the number ranged from 37 to 102. Planting in trenches filled with enriched growth medium + staking + fertigation through drip or microsprinkler system along with growing of a second storey long pepper crop above the ground planted ones in hanging pots with mist irrigation was found beneficial for increasing total spike number from all harvests. Spike yield per plant also showed a similar trend (Table Nos, 15, 16, 17; Fig Nos. 9 -17).

The spike number per plant is an important yield attribute governing the final yield. Long pepper requires heavy manuring for its growth and production. The slow growth of plants in control plots resulted in subsequent delay in bearing.

Plant productivity is influenced by the metabolic activities which require adequate amount of nutrients and moisture. Growth characters and canopy attributes reveal that long pepper crop responded very well to management practices. Nutrient and moisture supplying power of enriched growth medium along with proper leaf display created suitable habitats for improving plant productivity. Foliar fertilization has been tried as a means of supplying supplement doses of minor and major nutrients, plant hormones, stimulants and other beneficial substances. Observed effects of foliar fertilization include yield increases, resistance to disease and insect pests, improved drought tolerance and plant growth. Vermiwash application is reported to increase the growth and yield of crops such as marigold, chrysanthemum and tomato (Sebastian, *et al*. 2007). Yield increase might be due to supplementation of organic N, P & K along with micronutrients besides growth promoting effect of both solid and liquid organic manures (Sundaram and Udayakumar, 2006). Protected cultivation enhanced spike number and yield. Similar results have been reported on *Piper longum* plants grown under 50% shade (maximum instantaneous light intensity 850 micromol $m^{-2}s^{-1}$) compared to plants 25-75% shade respectively (Etampawala *et al*., 2002). Staking also enhanced spike number and spike yield per plant. Productivity increase due to staking has been reported in several crops. Okonmah (2011) reported that plant growth, yield and yield components were better under staking in cucumber than no staking and best with five meter raised platform staking method since the number of leaves, flowering, pollination and fruiting were well enhanced due to better display to receive more sunlight.

In African yam bean, highest seed yield was observed due to staking compared to nonstaking (Ogah, 2003).

A) 2 MAP

B) 3 MAP

C) 4 MAP

D) 5 MAP

Plate.3 Staking and drip system

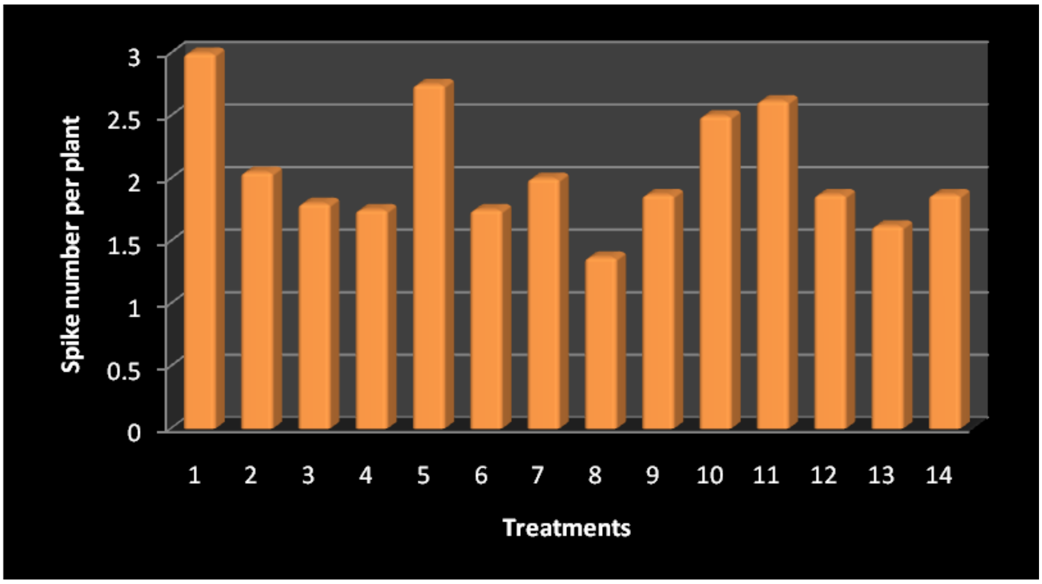

Fig.9 Spike number at 7 MAP as influenced by precision farming technique under protected cultivation

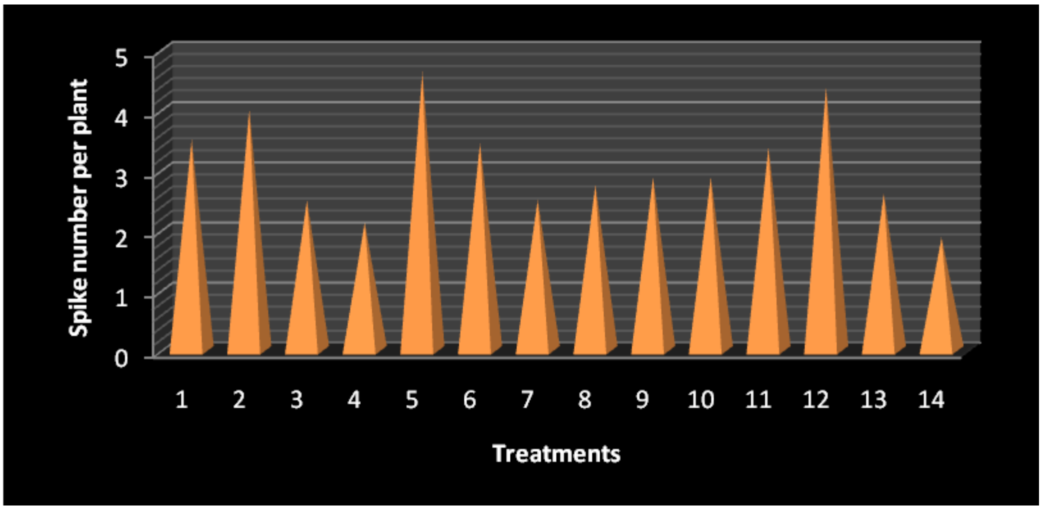

Fig.10 Spike number at 8 MAP as influenced by precision farming technique under protected cultivation

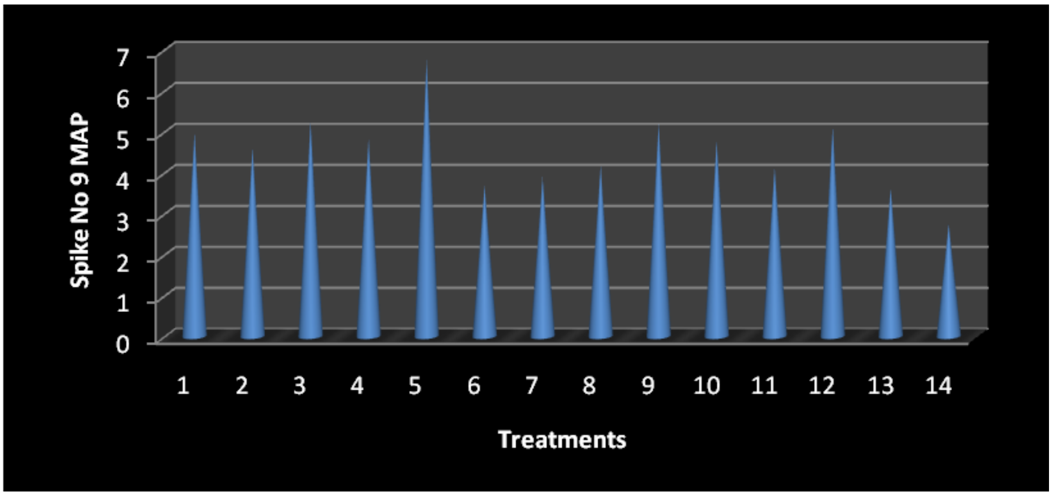

Fig.11 Spike number at 9 MAP as influenced by precision farming technique under protected cultivation

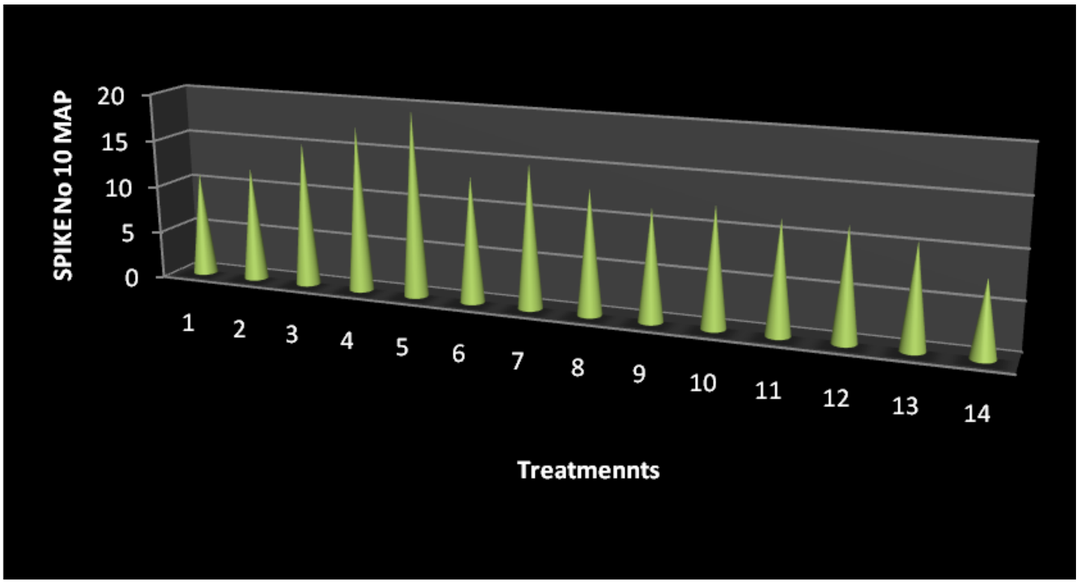

Fig.12 Spike number at 10 MAP as influenced by precision farming technique under protected cultivation

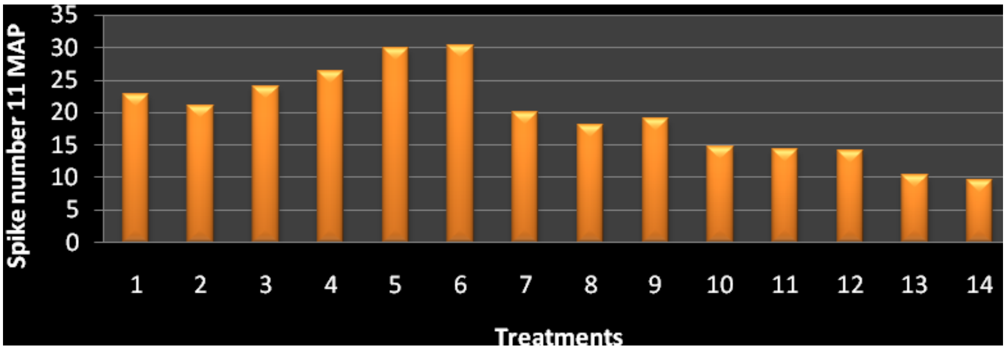

Fig.13 Spike number at 11 MAP as influenced by precision farming technique under protected cultivation

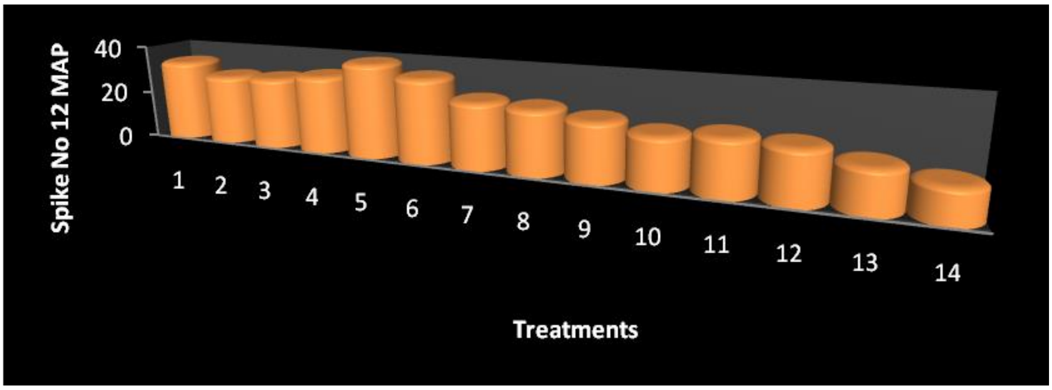

Fig.14 Spike number at 12MAP as influenced by precision farming technique under protected cultivation

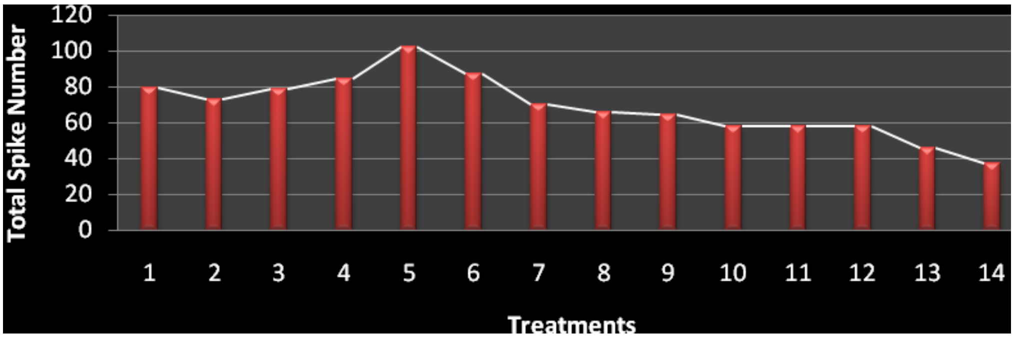

Fig.15 Total Spike number as influenced by precision farming technique under protected cultivation

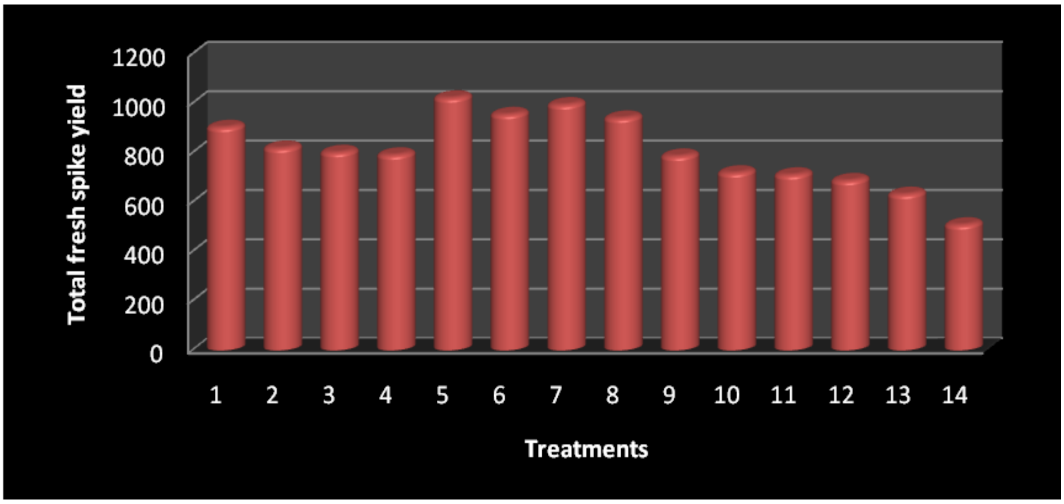

Fig.16 Total fresh spike yield (kg ha^{-1}) as influenced by precision farming technique under protected cultivation

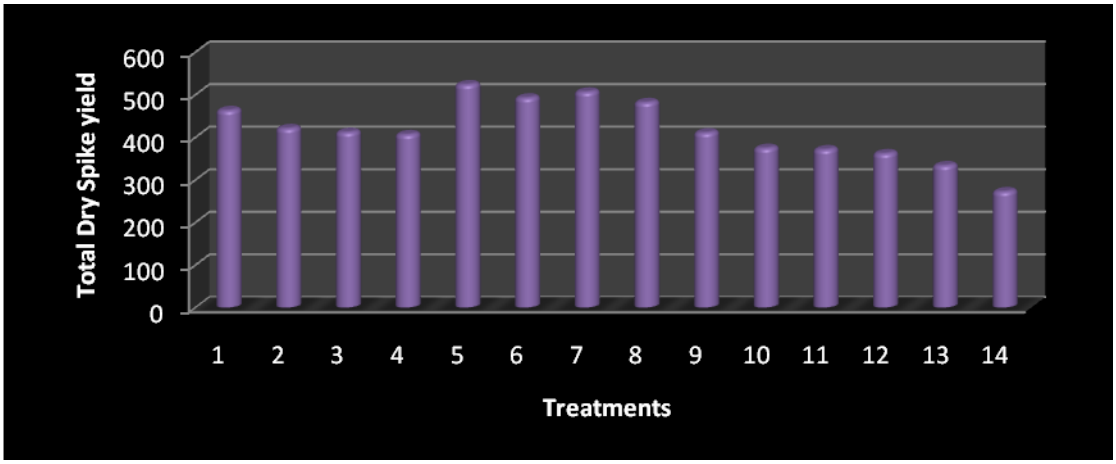

Fig.17 Total dry spike yield (kg ha^{-1}) as influenced by precision farming technique under protected cultivation

The yield increase might probably be due to the advantageous effects of staking which provided support for the numerous branches of the crop. Similar results have been reported by (Adeniyan *et al*., 2007). Hence, as a climbing crop, it needs a stake for proper vegetative growth (Milneredhead *et al.,* 1971).

5.5 TOTAL DRY MATTER PRODUCTION

Protected cultivation and precision farming technique significantly influenced total dry matter production at all stages of growth except 8 MAP. The treatments effect were inconsistent at various stages of growth. In general, planting long pepper in trenches filled with enriched growth medium + staking + fertigation through drip or microsprinkler system along with growing of a second storey long pepper crop above the ground planted ones in hanging pots with mist irrigation created favourable situations for enhancing total dry matter production (Table Nos 18 and 19).

Under life saving irrigation, dry matter production was reduced considerably due to the effect of water stress. Water deficits generally have a negative effect on the dry matter production in plants as it impairs many of the physiological processes which determine the growth. The reduction in dry matter production could be due to the decrease in the plant characters like vine length, number of branches, total leaf production and spike yield, which are positively correlated with the total dry matter production in different species.

Protected cultivation enhanced total dry matter production. The shade net reduced both the diurnal and seasonal fluctuations in soil temperature. Its principal effects on diurnal temperature is to reduce the mid day maximum temperature under hot and dry conditions. The soil under protection is much cooler during the heat of the day and rather warmer during the night. The shade net slows down the rate of evaporation from a wet soil considerably. The rate of evaporation is controlled by the proportion of energy absorbed by the soil which is used for evaporating water and by the rate of removal of water vapour from the region where it is being produced (Russell, 1982). From the present study, it is clear that protected cultivation and enriched growth medium conserve soil moisture on account of umpteen similar attributes.

5.6 Spike yield and quality

Total dry spike production ranged from 272-524 kg ha^{-1}. The highest dry spike yield of 524 kg ha^{-1} was recorded when long pepper was planted in trenches filled with enriched growth medium + staking + fertigation through drip system along with growing of a second storey long pepper crop above the ground planted ones in hanging pots with mist irrigation. Integrated management of long pepper involving enriched growth medium, staking, fertigation with drip system and maintenance of a second storey long pepper crop with mist irrigation under protected cultivation was found favourable for enhancing spike production to the tune of 48 per cent compared to the control. The alkaloid content ranged from 5.1-6.05 per cent. Total alkaloid production per hectare was found to be significantly influenced by treatment effects and it varied from 15.58 to 29.58 kg ha^{-1}. The highest alkaloid production of 29.5 kg ha^{-1} was recorded when integrated management was practiced as above. The reasons attributed to higher spike number and spike yield per plant under sections 3.8.1.1 are applicable for higher spike yield also. Higher production of alkaloid was due to higher spike yield per hectare (Table No 20; Fig Nos 18 and 19).

5.7 Nutrient uptake

Uptake of nitrogen and potassium was found to be significantly influenced by treatment effects though phosphorus uptake was unaffected by protected cultivation and precision farming techniques. It is the total dry matter production and the nutrient content that decides the total uptake. Wide variations in total dry matter production along with slight variations in nutrient concentration have resulted in differences in nutrient uptake. This is evident from (Table Nos 21 and 22 and Fig Nos 20 - 25).

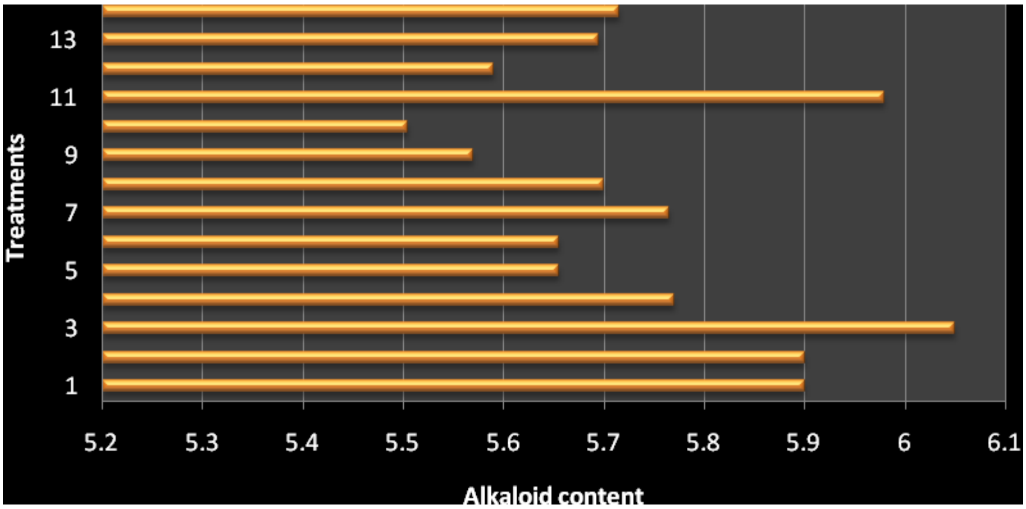

Fig.18 Alkaloid content (%) as influenced by precision farming technique under protected cultivation

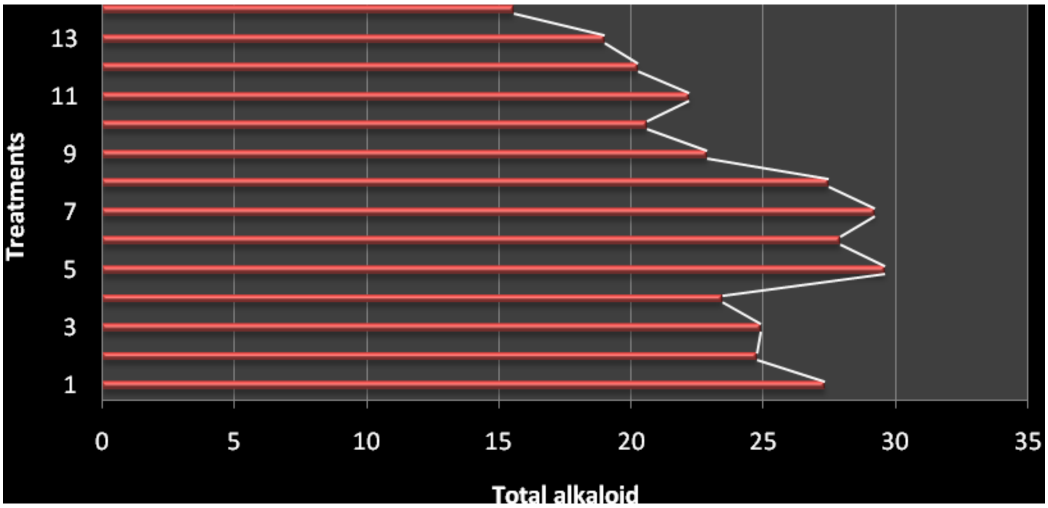

Fig.19 Total Alkaloid content (kg ha^{-1}) as influenced by precision farming technique under protected cultivation

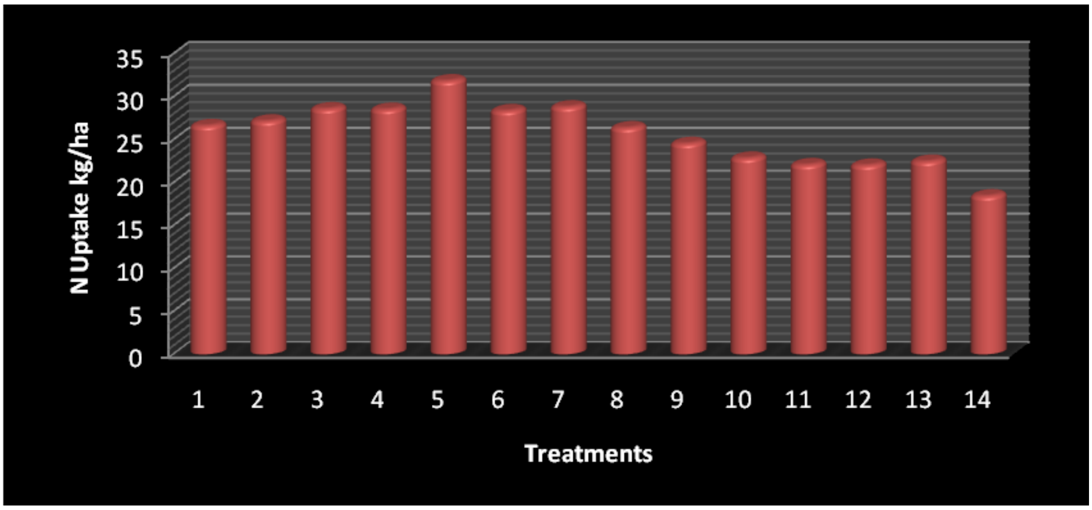

Fig.20 N uptake in leaf as influenced by precision farming technique under protected cultivation

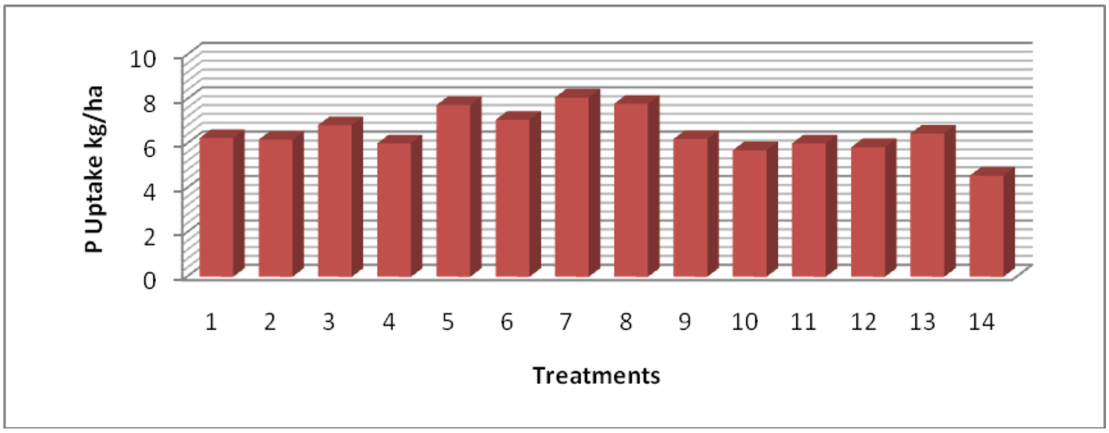

Fig. 21 P uptake in leaf as influenced by precision farming technique under protected cultivation

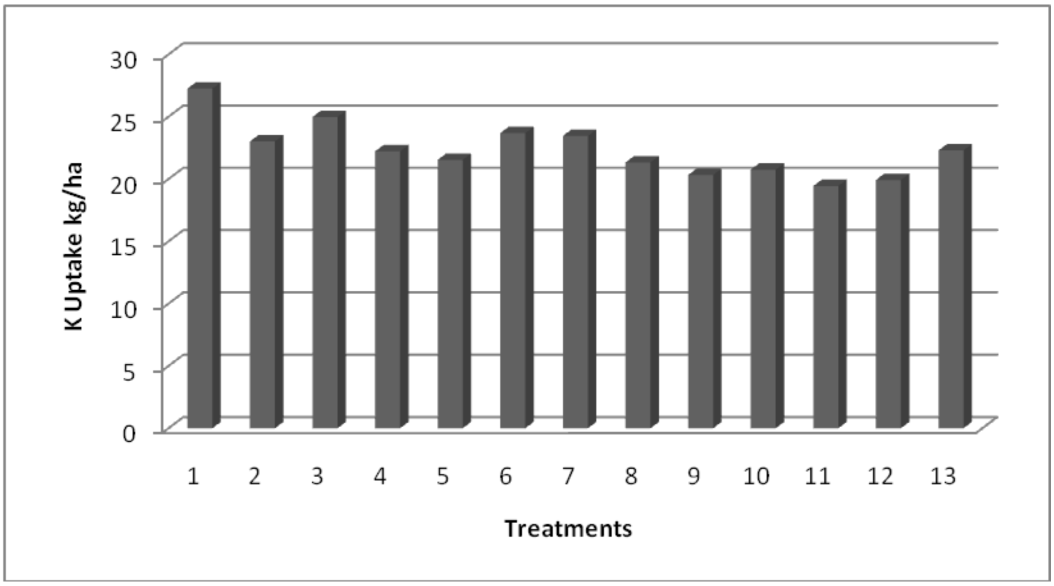

Fig. 22 K uptake in leaf as influenced by precision farming technique under protected cultivation

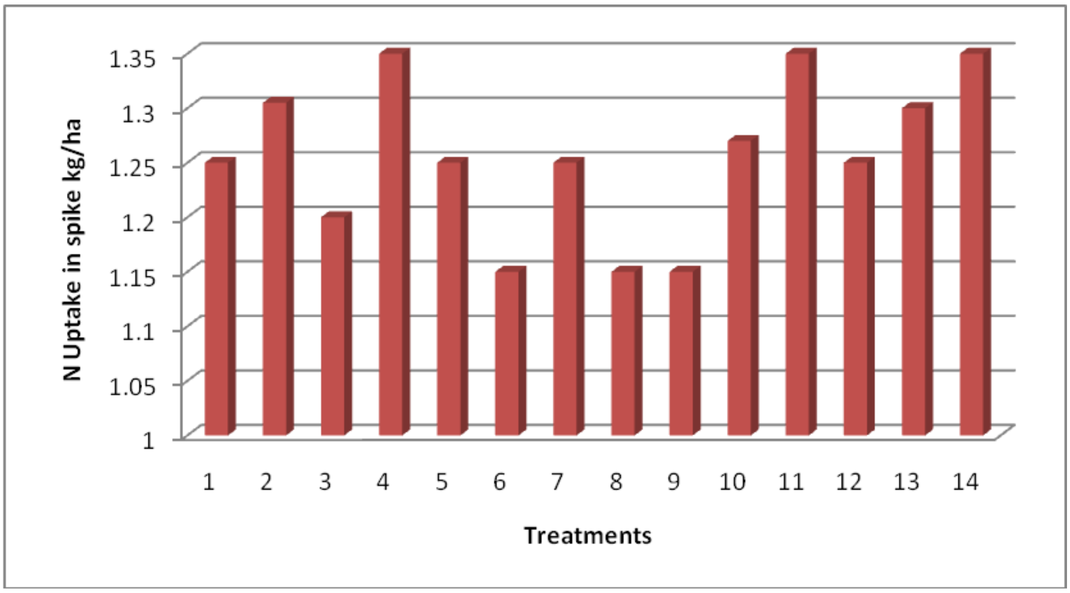

Fig. 23 N uptake in leaf as influenced by precision farming technique under protected cultivation

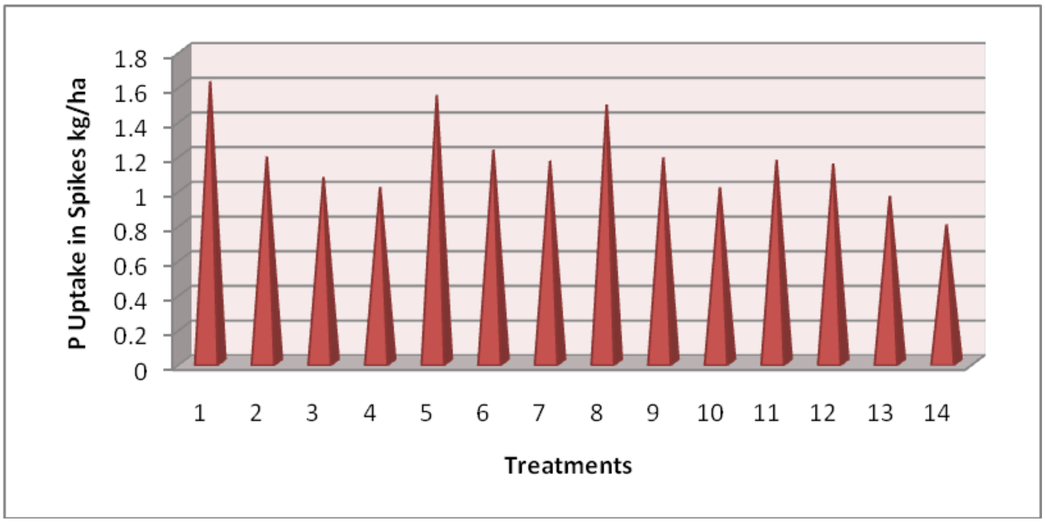

Fig. 24 P uptake in leaf as influenced by precision farming technique under protected cultivation

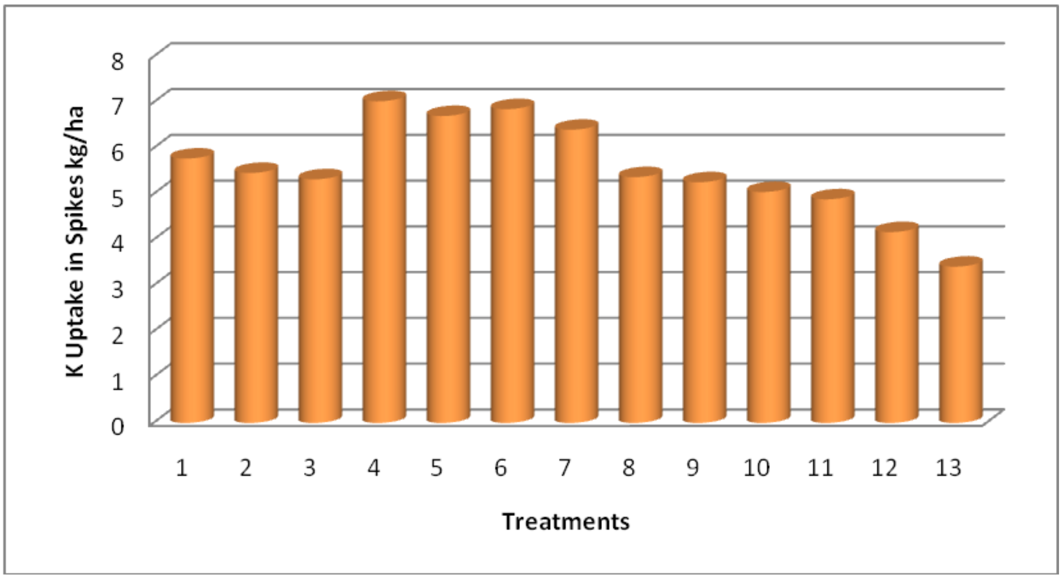

Fig. 25 K uptake in leaf as influenced by precision farming technique under protected cultivation

5.8 Soil moisture

Precision farming techniques on long pepper under protected cultivation influenced moisture content of the soil before and after irrigation, seasonal consumptive use, mean daily cu, crop coefficient, crop water use efficiency, field water use efficiency and water productivity. Except the two control treatments where life saving irrigation was practiced, all other treatments were on par with respect to seasonal consumptive use and mean daily consumptive use. The highest seasonal cu of 599 mm was recorded when long pepper was planted in trenches filled with enriched growth medium + without staking + fertigation through microsprinkler + planting in hanging pots + fertigation. The increase in seasonal consumptive use was to the tune of 70 per cent compared to the control. The highest mean daily cu of 1.64 mmwas recorded by the above treatment which was 71 per cent higher compared to the control.

The two control treatments which received life saving irrigation showed higher crop water use efficiency and FWUE. The highest CWUE of 2284 g M-3 was recorded when long pepper was planted in trenches filled with potting mixture and allowed to creep on the land surface and provided with life saving irrigation. The same treatment also showed the highest FWUE and showed significant superiority over all other treatments. All the treatments which received microirrigation were on par in relation to water productivity (Table 23; and Fig Nos, 26 - 31).

Plate.4 Micro sprinkler irrigation at 10 MAP

A) Whole plant

B) Spike in every leaf axil

Plate 5. Performance of long pepper in T_5

A) Lateral connected to main

B) Filteration unit

C) Fertigation tank

D) Emitters installed

Plate 6. Components of drip system

A) Mist irrigation

B) Long pepper in hanging pots

C) Performance under T_8

D) Performance under T_5

Plate 7. Mist irrigation in hanging pots

A) Just after planting

B) Imposition of different treatments

C) Hanging pots in T5

D) Spike production in hanging pots

Plate 8. Protected cultivation

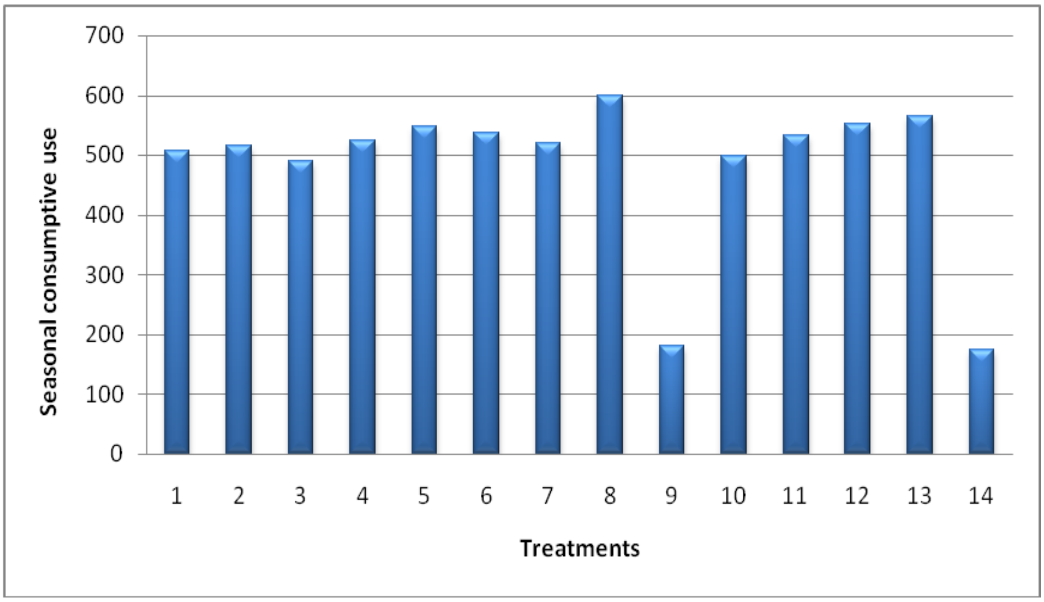

Fig. 26 Seasonal consumptive use (mm) as influenced by precision farming techniques under protected cultivation

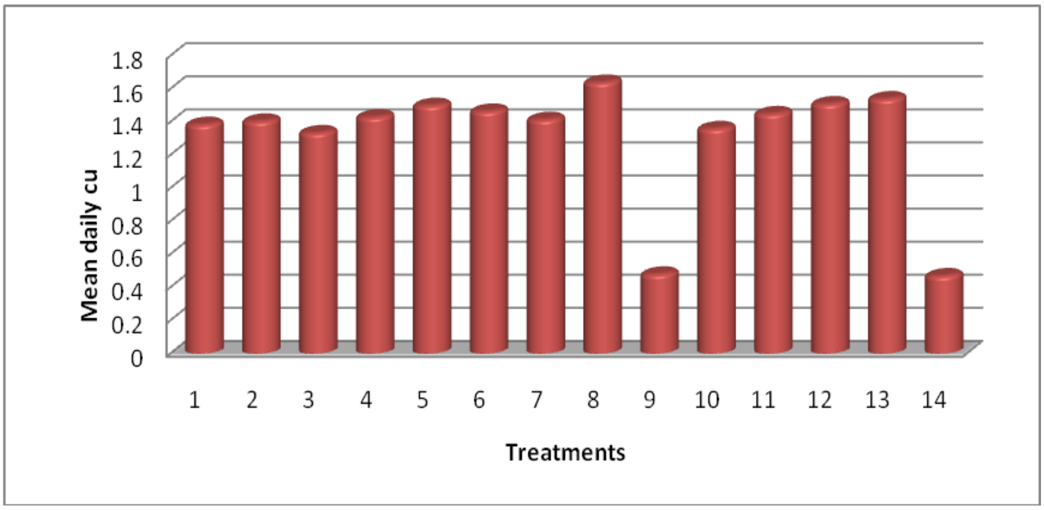

Fig. 27 Mean daily consumptive use (mm) as influenced by precision farming techniques under protected cultivation

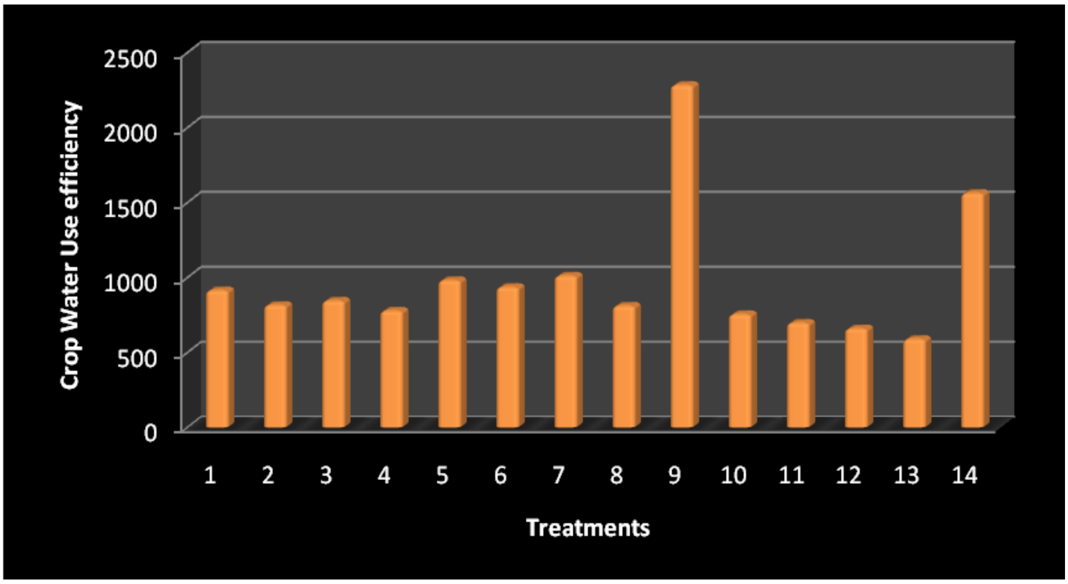

Fig. 28 Crop water use efficiency (gm^{-3}) as influenced by precision farming technique under protected cultivation

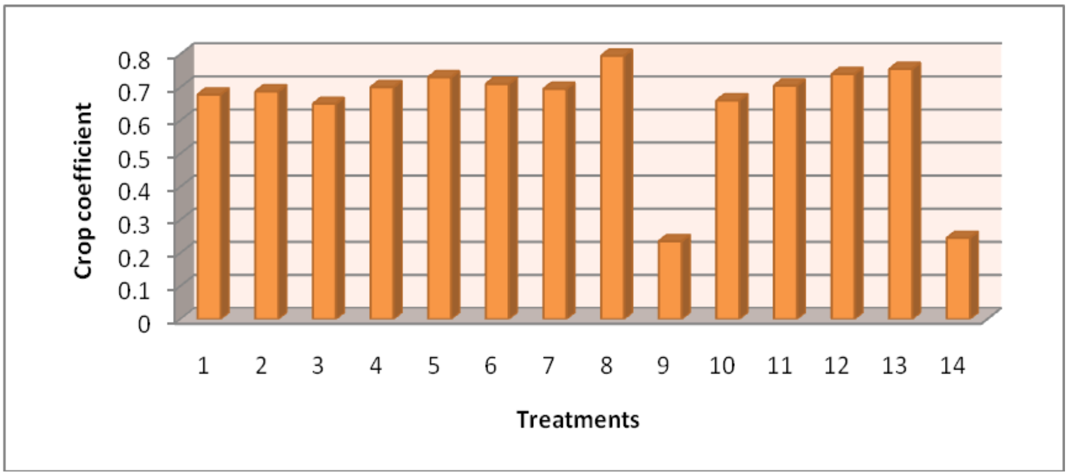

Fig. 29 Crop coefficient as influenced by precision farming technique under protected cultivation

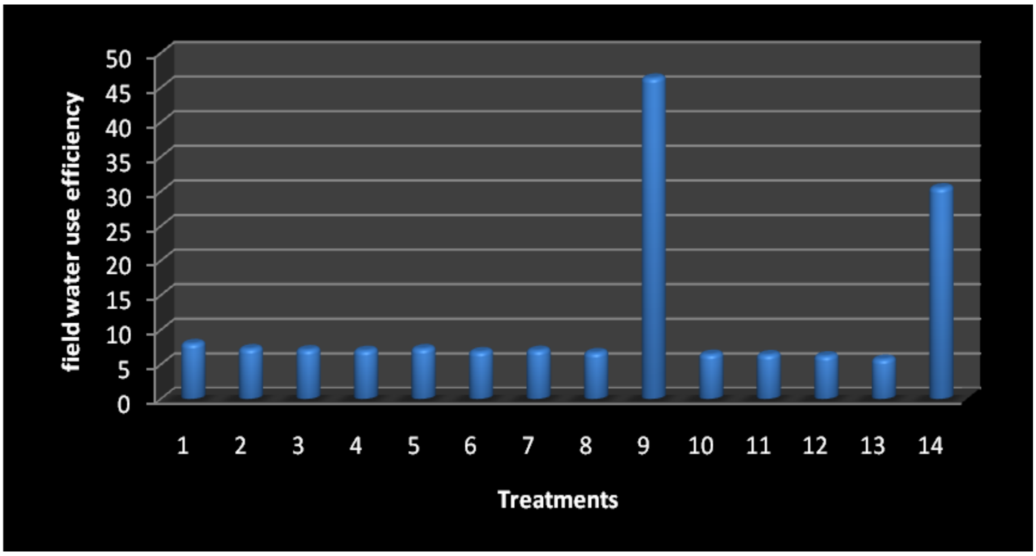

Fig. 30 Field water use efficiency (gm^{-3}) as influenced by precision farming techniques under protected cultivation

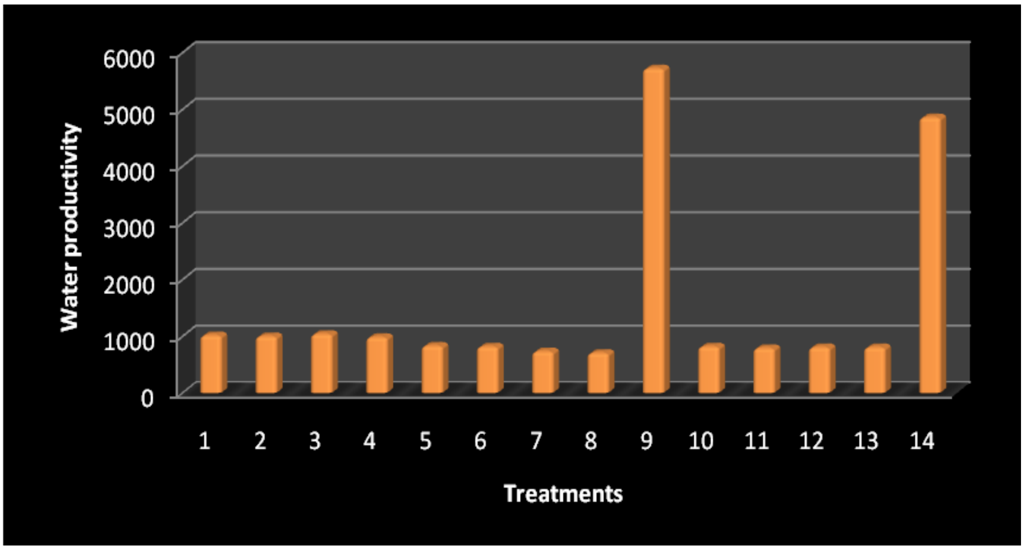

Fig. 31 Water productivity (gm^{-3}) as influenced by precision farming technique under protected cultivation

5.9 Economic analysis

The gross income from long pepper cultivation showed significant variation due to treatment effects and it ranged from 1.91 lakh ha^{-1} to 3.7 lakh ha^{-1}. The treatment, where integrated management (enriched growth medium + staking + fertigation through drip system + planting in hanging pots and fertigation) was practiced recorded the highest gross income of 3.7 lakh ha^{-1} which was 47 per cent higher compared to the control. The above management programme was found superior with respect to generation of net income to the tune of Rs. 1.9 lakh ha^{-1} compared to the control. In fact, similar management programme was found beneficial in increasing BCR to the tune of 2.06 though it varied from 1.7 to 2.06 (Table No 24; and Fig Nos, 32 - 34).

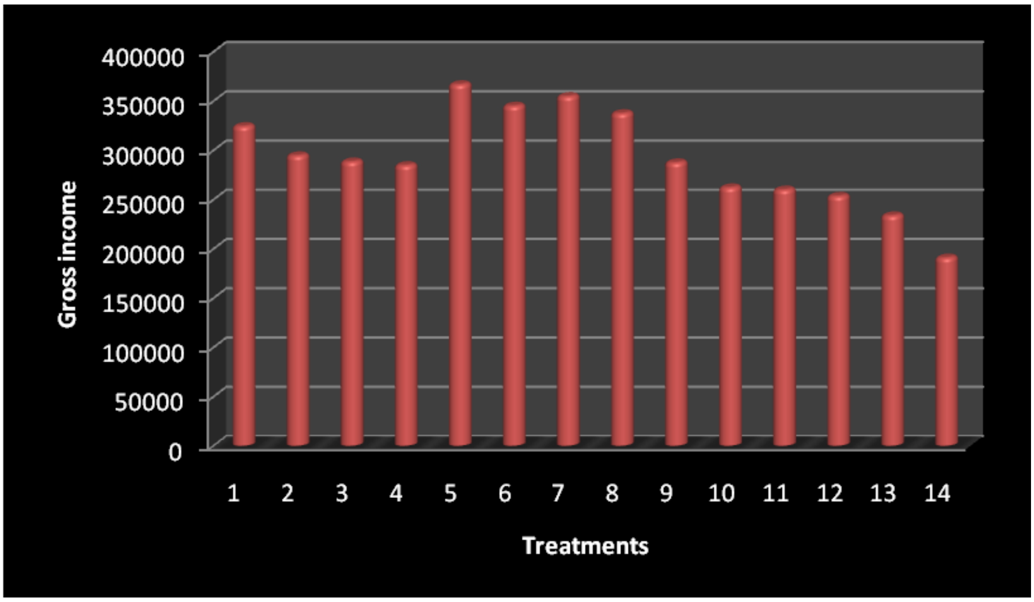

Fig. 32 Gross income (Rs ha^{-1}) as influenced by precision farming techniques under protected cultivation

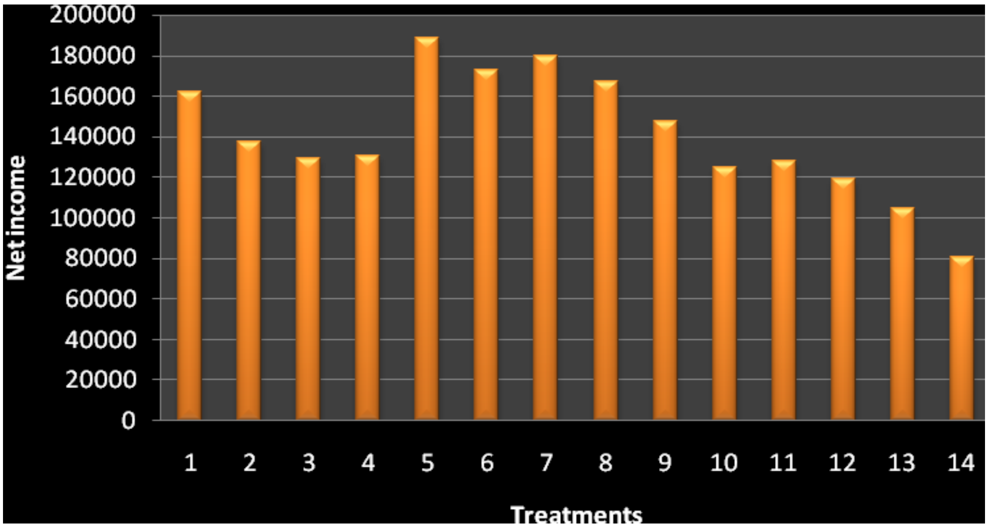

Fig. 33 Net income (Rs ha^{-1}) as influenced by precision farming techniques under protected cultivation

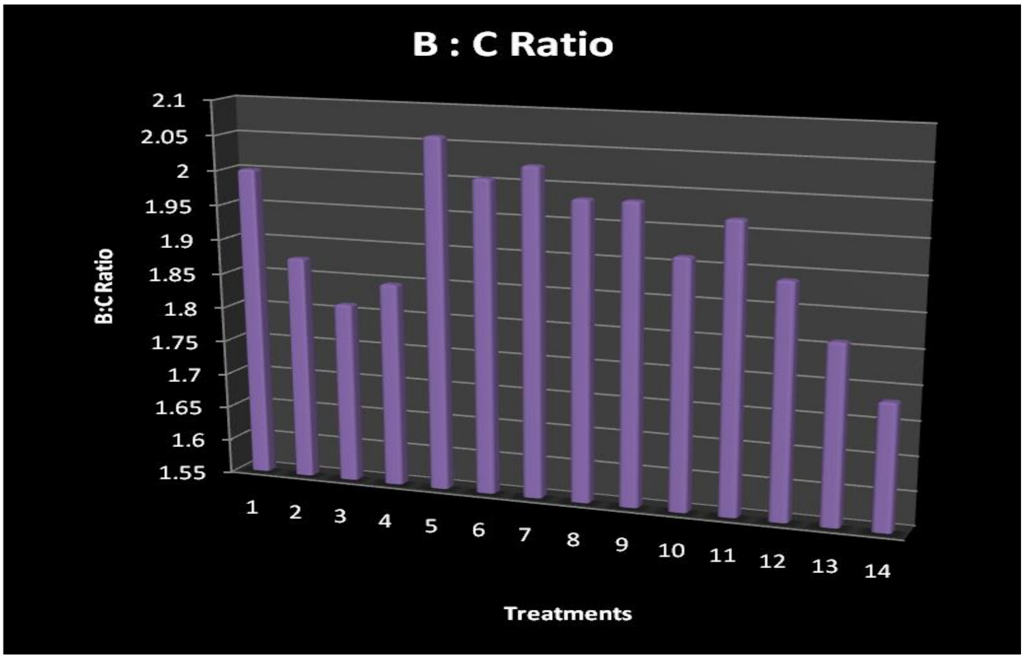

Fig. 34 B: C ratio as influenced by precision farming techniques under protected cultivation

SUMMARY

6. SUMMARY

Vine length at all stages of growth except at 12 MAP was found to be significantly influenced by treatments. However the highest vine length of 272 cm was recorded by treatment T6 which was 0.73 per cent higher over the control, T14.

The treatments exerted significant effects on the total number of leaves at all stages of growth. The treatment T1 recorded the highest leaf number (119.8) at 12 MAP and the per cent increase over control was 10.58.

Branching in long pepper was found to be significantly influenced by treatment effects only during early stages of growth ie, at 7 and 8 MAP. Though not significant T7 exerted highest number of branches (4.6) at 12 MAP.

The effect of protected cultivation and precision farming techniques was not consistent in influencing root number. It resulted in significant effect on root number at 7 and 10 MAP. Though not significant T9 at 12MAP recorded the highest root number (53.67).

The effect of treatments on root length was spectacular at all stages of growth. At 12 MAP, T4 registered 35.26 per cent increase in root length compared to control.

The effect of treatments on root spread was not consistent at all stages of growth. T1 registered highest root spread of 30.30 cm at 12 MAP which was 17.01 per cent higher compared to control.

Significant influence of treatments on root fresh weight was observed at 9 and 12 MAP only. At 12 MAP the per cent increase in root fresh weight in T3 was 11.60 per cent compared to the control. The significant influence of treatments on root dry weight was evident only at 12 MAP. At 12 MAP, T4 on par with T5, T3, T10, and T6 recorded the highest root dry weight which was 19.75 per cent higher compared to control.

Leaf chlorophyll a ranged from 0.6-2.3 mg g^{-1} fresh leaf. The treatment T5 recorded the highest chlorophyll a content of 2.38 mg g^{-1} fresh leaves which was on par with T7, T1, T6, T8, T2, T3 and T9 compared to the control treatment T14. The treatment T5 recorded 73.5 per cent increase in chlorophyll a content. The trend was almost similar with respect to chlorophyll b as well.

Carotenoids also showed significant variation with respect to treatment effects and its content ranged from 5.9-21.9 mg g^{-1} fresh leaf. T5 recorded 21.91 mg g^{-1} fresh leaf which was 72.7 per cent higher compared to control.

Relative leaf water content was found to be significantly influence by treatment effects at 12 MAP. The treatment T6 which was found to be on par with T5, T8, and T2 recorded the highest relative leaf water content (86.05 %) which 39.73 per cent higher compared to control.

Significantly influence of treatments was evident on PAR observed at 12 MAP. The control treatment T14 recorded the highest value.

Total solar radiation recorded at 12^0clock ranged from 329-1903 KW m^{-2}. The maximum value was recorded by the treatment T13.

Total solar radiation recorded at 2^0clock ranged from 252-1270 KW m^{-2}. The maximum value was recorded by the treatment T10 and it was significantly different from all other treatments.

Spike number (7, 8, 9, 10, 11 and 12 MAP) per plant was found to be significantly influenced by treatments effects at all stages of growth. At 7 MAP the treatment T1 recorded the highest spike number and it was 54.16 per cent higher compared to control.

At 7 MAP the treatment T1 recorded the highest spike number which was 37.66 per cent higher compared to control. However, the trend was slightly different at all other stages.

The treatment T5 recorded the highest spike number at 8, 9, 10 and 12 MAP where as T6 was found to be superior at 11 MAP. T14 registered the lowest value at all stages of growth.

T5 recorded 6.78 number of spikes at 9 MAP, which was 59.43 per cent higher compared to control. The treatment showed significant superiority when compared to all other treatments. The same treatment T5, again showed significant superiority at 10 MAP and recorded 60.05 per cent higher spike number compared to control.

T6 showed significant superiority at 11 MAP compared to all other treatments and increase in spike number was the tune of 68.31 per cent compared to control, T14.

Similar to treatment effects at 8, 9, 10 MAP, T5 again showed highest spike number at 12 MAP which was on par with T6 and T11 and 65.67per cent higher compared to control.

The highest total spike number was recorded by the treatment T_5 and it was found to be on par with T_6. The percent increase in spike number in treatment T_5 was 63.69 per cent over the control, $T_{14.}$

Protected cultivation and precision farming techniques significantly influenced fresh spike yield per plant at all stages of harvest. T7 at 6 MAP and T5 at all other stages of harvest i.e. 8, 10 & 12 MAP showed the highest values. At 6 MAP T7 registered highest value which was 38.30 per cent higher compared to T14. The trend was slightly different at all the stages of harvest.

At 8 MAP, T5 was significantly different from all other treatments and increase in yield was 50.83 per cent over the control. Though T_5 showed higher yield at 10 MAP it was on par with T7 and T8 and the percent increase in yield recorded was tune of 56.58 per cent over control.

T5 which was on par with T7, T6, T1 and T8 at 12 MAP showed significantly higher yield and the increase was 48.1 per cent compared to control.

Similar to fresh spike yield the dry spikes yield kg ha^{-1} was also found to be significantly influenced by protected cultivation and precision farming techniques and the trend was exactly similar to fresh spike production.

Protected cultivation and precision farming technique significantly influenced total biomass (fresh) production at all stages of growth from 7 - 12 MAP except at 8 MAP. In general, the treatment effects were inconsistent at various stages of growth. T5 on par with T4 and T12 at 7 MAP, T5 at 9 MAP, T6 at 10 MAP; and T5 at 12 MAP recorded significantly higher biomass production.

Total dry matter production was also found to be significantly influenced by protected cultivation and precision farming techniques and the trend was exactly similar to total biomass production.

Total spike production ranged from 272-524 kg ha^{-1}. The highest dry spike yield of 524 kg per hectare was recorded by the treatment T5. The increase in spike production in T5 was 47.96 per cent higher over the control.

The alkaloid content ranged from 5.12 to 6.05 per cent. Total alkaloid production per hectare was found to be significantly influenced by treatment effects and it varied from 15.58 to 29.58 kg ha^{-1}. The highest alkaloid production of 29.5 kg ha^{-1} was recorded by treatment T_5 which 47.32 per cent higher compared to the control.

Uptake of nitrogen and potassium was found to be significantly influenced by treatment effects. However, phosphorus uptake was unaffected by protected cultivation and precision farming techniques.

T_5 recorded the highest uptake of N which was found to be 42.08 % higher compared to the control. Though phosphorus uptake was unaffected by treatment effects, T_7 recorded the highest uptake of 8.90 kg ha^{-1} which was 43.53 per cent higher compared to the control, T14. With respect to potassium uptake, T_1 and T_3 were on par and increase recorded by T_1 over the control T_{14} was 31 per cent.

N and K accretion in spikes were found to be significantly influenced by treatment effects. T_5 recorded the highest uptake of 6.503 kg N ha^{-1}.

With respect to potassium uptake T_5 was found to be superior and was on par with T_7 and T_6. The per cent increase in K uptake over control $T_{14,}$ was 51.40.

The treatments effects had significant influence on soil moisture content after irrigation and the values ranged from 18.85 - 20.85 per cent. The treatment T5 recorded the highest moisture content after irrigation. However, soil moisture estimation prior to irrigation revealed no significant difference due to treatment effects.

Seasonal consumptive use and mean daily consumptive use also showed significant variation due to treatment effects. Except the two control treatments, T9 and T14; all the other 12 treatments where micro irrigation systems were installed were on par.

The two control treatments, T9 and T14, which received life saving irrigation showed higher crop water use efficiency and FWUE.

All the treatments which received micro irrigation were on par in relation to water productivity. The control treatments T9 and T14 registered the highest water productivity of 572.44 g m^{-3} which differed significantly from all other treatments.

The Gross income from long pepper cultivation showed significant variation due to treatment effects and it ranged from 1.91 lakh per ha to 3.7 lakh per ha. The treatment, T5 recorded the highest gross income of 3.7 lakh per ha.

With respect to net income the treatment T5 on par with T7 and T6 showed highest value and differed significantly from all other treatments.

Similar to gross income and net income, the highest B : C ratio of 2.06 was registered by T5 and it was on par with T7, T6, T1, T5, T8 and T11. Compare to the control treatment the treatment T5 recorded 18.39 per cent increase B: C: R.

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PRECISION FARMING TECHNIQUES IN LONG PEPPER (*Piper longum* L.) UNDER PROTECTED CULTIVATION

by

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Abstract of the
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ABSTRACT

Piper longum, popularly known as thippali or long pepper, is an economically important medicinal plant well adapted to the agro climatic situations prevailing in the state. Generally, long pepper is grown in the interspaces of coconut gardens or under partial shade. But the productivity of the crop varies widely with habitats. So it is necessary to maintain a favourable microclimate throughout the growth stages of long pepper. Protected cultivation is one of the measures that can be adopted to ensure an ideal habitat for improving the growth and productivity of long pepper.

The experiment entitled "Precision farming techniques in long pepper (*Piper longum* Linn.) under protected cultivation" was carried out at the College of Agriculture, Padannakkad, Kasaragod, Kerala during 2013-2014 to develop cost effective agro techniques for improving the quality attributes, productivity and profitability of long pepper.

The experiment consisting of 14 treatments replicated twice was laid out in RBD in the interspaces of coconut garden. The treatments were, T1 - Planting in trenches filled with enriched rooting medium + Staking + Fertigation through drip system, T2- Planting in trenches filled with enriched rooting medium + Staking + Fertigation through micro sprinkler, T3- Planting in trenches filled with enriched rooting medium + Without Staking + Fertigation through drip system, T4- Planting in trenches filled with enriched rooting medium + Without Staking + Fertigation through micro sprinkler, T5 - T1 + Planting in hanging pots and fertigation through mist, T6 - T2 + Planting in hanging pots and fertigation through mist, T7 - T3 + Planting in hanging pots and fertigation through mist, T8 - T4 + Planting in hanging pots and fertigation through mist, T9 - Planting in trenches filled with potting mixture + Without staking + Life saving irrigation (Control), T10 - T1 Under partial shade, T11- T2 Under partial shade, T12- T3 Under partial shade, T13- T4 Under partial shade, T14- Planting in trenches filled with potting mixture + Without staking + Life saving irrigation under partial shade (Control).

Treatments had no significant effect on vine length. However the highest vine length was recorded by the treatment T6. The treatments exerted significant effect on the total number of leaves at all stages of growth. At 12 MAP, the treatment T1 recorded the highest leaf number. Branching in long pepper was found to be significantly influenced by treatment effects only during the early stages of growth ie, at 7 and 8 MAP.

The effect of protected cultivation and precision farming techniques was not consistent in influencing root number at various stages of growth. However, significant difference in root number was registered at 7 and 10 MAP. Though not significant, T9 at 12 MAP recorded the highest root number. The effect of treatments on root length was spectacular at all stages of growth. T4 on par with T3 recorded the highest root length at 12 MAP. Though, the effect of treatments on root spread was not consistent at all stages of growth, significant influence of treatments was evident at 9, 10, and 11 MAP. The treatment T1 registered the highest root spread at 12 MAP. The significant influence of treatments on root dry weight was evident only at 12 MAP where T4 which was on par with T_5, T_3, T_{10}, and T_6 recorded the highest root dry weight.

Physiological and biochemical characters were also found to be significantly influenced by treatment effects at 12MAP. The treatment T_6 which was on par with T_5, T_8, and T_2 recorded the highest relative leaf water content. The treatment T_9 registered highest leaf chlorophyll content at 12 MAP.

The highest total spike number per plant per year was recorded by the treatment T_5 and it was found to be on par with T_6. The per cent increase in spike number in treatment T_5 was 63.69% over control. The highest total fresh and dry spike yield of 1023 and 524 kg ha^{-1} were recorded by the treatment T_5. Total alkaloid production per hectare varied from 15.58 to 29.58 kg ha^{-1}.The treatment, T_5 recorded the highest alkaloid production. Uptake of nitrogen and potassium was found to be significantly influenced by treatment effects. But phosphorus uptake was unaffected by the treatment effects.

With respect to seasonal consumptive use, mean daily consumptive use and crop coefficient, all the treatments under protected cultivation and precision farming techniques were on par and recorded significantly higher values compared to the two control treatments, T9 and T14. However, the treatments under protected cultivation and precision farming techniques were on par in relation to water use efficiency and water productivity. The economic analysis of the system revealed the superior performance of the treatment T5 with respect to gross income, net income and BCR.

It is concluded that integrated management of long pepper by planting rooted cuttings of the variety ‘Viswam’ in trenches filled with enriched rooting medium (dry powdered cowdung + vermicompost + composted coir pith + bone meal in 1:1:1:1 proportion enriched with Trichoderma, Azospirillum and Pseudomonas) at a spacing of 50 x 50 cm, trailing on cassava stakes, fertigation, ie, rotational application of liquid organic manures, ie, vermiwash, panchagavya and jeevamrutha through drip irrigation system and maintaining a second storey of long pepper in hanging pots with mist irrigation in a shade house erected in the interspaces of coconut garden (protected cultivation) was found beneficial to improve the quality, productivity and profitability of long pepper in the humid tropics.

Appendix

Appendix I

Weather data during the crop period

Period	Maximum temperature (^{0}C)	Minimum temperature (^{0}C)	Rainfall (mm)	Total Sunshine hours	Relative humidity (%)	Evaporation (mm)
May	34.58	26.23	79.9	174.6	70.20	4.80
June	29.90	22.49	1343.9	43.4	82.73	1.70
July	30.23	23.74	1222.3	19.1	86.36	1.68
August	30.39	23.78	382.3	84.8	82.30	3.01
September	30.02	23.00	185.3	103.00	78.00	2.91
October	31.77	22.97	229.1	129.9	78.36	2.83
November	32.53	20.81	5.2	191.9	65.26	3.40
December	33.49	19.69	13.8	279.60	58.30	3.30
January	32.59	20.30	0.00	258.50	58.81	3.53
February	32.9	21.4	0.00	209.3	61.20	4.40
March	33.2	22.2	0.00	238.5	61.40	5.00
April	34.4	25.1	0.00	186.9	65.2	5.20