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SOURCE EFFICACY OF NUTRIENTS AND FERTIGATION IN LONG PEPPER (*Piper longum* L.)

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"SOURCE EFFICACY OF NUTRIENTS AND FERTIGATION IN LONG PEPPER (*Piper longum* L.)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society

Padannakkad

Date 30 06 2016

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CERTIFICATE

Certified that this thesis entitled **"SOURCE EFFICACY OF NUTRIENTS AND FERTIGATION IN LONG PEPPER (*Piper longum* L.)."** is a record of research work done independently by Mr Abhimannue T R under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him

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LIST OF ABBREVIATIONS

%	-	Per cent
@	-	At the rate of
^{0}C	-	Degree Celsius
BCR	-	Benefit cost ratio
cc	-	Cubic centimeter
CD	-	Critical difference
cfu	-	Colony forming unit
cm	-	Centimeter
CO_2	-	Carbon dioxide
Cu	-	Consumptive use
CWUE	-	Crop water use efficiency
et al	-	And others
Fig	-	Figure
FWUE	-	Field water use efficiency
FYM	-	Farmyard manure
$g\ cc^{1}$	-	Gram per cubic centimeter
g	-	Gram
gm^{3}	-	Gram per cubic meter
ha^{1}	-	Per hectare
K	-	Potassium
K_2O	-	Potash
Kc	-	Crop coefficient
$kg\ ha^{1}$	-	Kilogram per hectare
kg	-	Kilogram
LAD	-	Leaf area duration
LAI	-	Leaf Area Index

mmol m ^{2} s ^{1}	-	Milli mole per metre square per second
m^2	-	Square metre
m^3	-	Cubic metre
Mai	-	Moisture after irrigation
MAP	-	Months after planting
Mbi	-	Moisture before irrigation
mg	-	milligram
ml	-	Millilitre
mm	-	Milli meter
MSL	-	Mean sea level
N	-	Nitrogen
NS	-	Not significant
P	-	Phosphorus
P_2O_5		Phosphate
PAR	-	Photosynthetically active radiation
ppm	-	parts per million
RLWC	-	Relative Leaf Water Content
Rs	-	Rupees
SE	-	Standard error
t ha ^{1}	-	Tonnes per hectare
UV	-	Ultraviolet
v/v	-	Volume / volume
viz	-	Namely
w/w	-	Weight / weight
yr ^{1}	-	Per year
RDF	-	Recommended dose of fertilizer

INTRODUCTION

1. INTRODUCTION

Long pepper (*Piper longum* L) is an economically important medicinal crop widely recommended for commercial mediculture among the progressive farmers of the state 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

The productivity of long pepper varies widely with habitats and weather variations 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 further 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

Fertigation with liquid organic manures through micro irrigation systems, *viz* , drip or micro sprinkler ensures proper modulation of rhizosphere to sustain optimum vegetative and reproductive growth Presence of macro and micro nutrients, hormones, vitamins, enzymes and other plant growth promoting substances in liquid organic manures makes them well suited for organic agriculture Apart from this, liquid organic manures can positively influence soil physical properties and well supports rhizosphere micro flora The negative impact of chemical fertilizers on soil can be alleviated by the proper utilization of these liquid organic manures

Crop nutrition is one of the important factors that influence the growth, development and yield of crops The critical stages of nutrient requirement in long pepper are initiation of flower primordia, flower emergence, spike formation and development 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 Adoption of micro-irrigation methods, *viz*, sprinkler or drip is one of the viable options available to ensure application of small and controlled amount of fertilizers as per the crop requirement in contrast to large amount of fertilizers placed on the bed at the beginning of the season

Investigations on soil based plant nutrient management plan for agro ecosystems of Kerala conducted by the Kerala State Planning Board revealed the deficiency of Magnesium, an essential secondary nutrient, in three fourth of the composite soil samples drawn from the state and tested Among the investigated micronutrients, the deficiency of boron only is significant and extensive, requiring immediate intervention Possibilities of application of these nutrients through fertigation are to be explored for achieving higher use efficiency without soil contamination

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 The only option available is to introduce long pepper into the existing cropping systems Introduction of long pepper in coconut gardens as an intercrop is feasible and remunerative It helps to augment income from coconut gardens

Commercial mediculture with long pepper by adopting appropriate micro-irrigation and fertigation techniques under poly cum shade house in coconut garden may help a long way to achieve higher productivity in a sustainable way Hence, the present investigation was undertaken to study the effect of micro irrigation and fertigation with water soluble fertilizers, liquid organic manures and plant growth promoting rhizobacteria on the growth, productivity, quality and economics of intercropped long pepper under poly cum shade house in coconut garden

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

In Kerala, production of long pepper is not sufficient to meet the ever increasing demand of ayurvedic medicine manufacturing units Hence, there is an urgent necessity to step up the production of long pepper It is one of the economically important crops recommended for commercial cultivation in the interspaces of coconut garden There are umpteen measures to step up the production of long pepper Micro irrigation, fertigation and shade regulation can help a long way to unlock the production potential of intercropped long pepper in the coconut gardens

The investigation entitled 'source efficacy of nutrients and fertigation in long pepper (*Piper longum* L)' was undertaken to study the effect of micro irrigation and fertigation with water soluble fertilizers, liquid organic manures and plant growth promoting rhizobacteria on the growth, productivity, quality and economics of intercropped long pepper under poly cum shade house in coconut garden The literature pertaining to the subject with special reference to long pepper are reviewed hereunder Wherever sufficient literature on long pepper are not available, studies on related crops and cropping situations are also reviewed

2 1 THE CROP LONG PEPPER

Long pepper (*Piper longum*) commonly known as "Thippali" is an underexploited crop of family *piperaceae* It is well known for its medicinal properties Availability of the crop is limited in domestic and international markets and the demand itself makes it as a commercially important crop It is widely distributed in the tropical regions of the world In India, long pepper is cultivated in West Bengal, Assam, Orissa, Maharashtra, Karnataka, Tamil Nadu and Kerala

Medicinal properties of long pepper are wide and most of the ayurvedic preparations contain long pepper extracts Dried unripe female spikes and roots possess medicinal properties Spikes contain pungent alkaloid called piperine Fruits also contain amino acids *viz*, L tyrosine, L cysteine and L aspartic acid and one per cent volatile oil, which exhibits certain anti-bacterial properties Decoction prepared from immature fruits is used for curing respiratory disorders (Zaveri *et al*, 2010) The dried spike contains more than twenty alkaloids *viz*, piperine, methyl piperine, iperonaline, piperettine, piperlongumine etc Long pepper is also used as flavouring agent in some parts of Asia Fruit has a capacity to prevent fever, jaundice, leprosy, bronchial asthma and malaria Pipal arishta, panchakola and trikatu are some of the preparations made from dried long pepper spikes

Botanically long pepper is a slender creeping dioecious perennial Erect branches arising from the shoots bear creamy white coloured immature spikes which turn gradually into dark green at maturity Matured unripe short stout female spikes are the officinal parts Spikes are born opposite to sessile leaves

2 2 MICRO CLIMATIC REQUIREMENTS OF LONG PEPPER

Long pepper is a crop which requires shade for its optimum growth It is a shade loving crop and flourishes well under tropical rain forests Exposure to sunlight causes scorching and yellowing there by reduces growth and yield So, shade management is essential for obtaining a good crop stand Micro climatic conditions inside a coconut garden is suitable for the cultivation of long pepper Poly cum shade house erected in the interspaces of coconut garden can be used for commercial cultivation of long pepper (Jayanth *et al*, 2015)

Height of plant, collar diameter, number of leaves per plant and leaf chlorophyll content are found to be higher in long pepper plants grown under medium shade (50 per cent shade) compared to low (25 per cent shade) and deep shade (75 per cent shade) Reason for reduced growth and yield of long pepper plants in sunlight is due to photo oxidation of chlorophyll (Etampawala *et al*, 2002)

Compared to shaded condition, under open condition, leaf production was minimum in bush pepper due to the scorching and wilting of leaves (Asha, 1986) In bush pepper, length and number of primary and secondary branches showed an increasing trend according to the decrease in light intensity from 100 per cent to 50 per cent Maximum length of primary and secondary branches and number of leaves were observed at 50 per cent light This may be due to the lesser photosynthetically active radiation obtained under shaded condition favouring growth (Devadas and Chandini, 2000)

2 3 ROLE OF WATER

Irrigation can positively influence growth, quality and yield in long pepper Irrigating at IW/CPE 1 0 is optimum for growth of long pepper (Manjunatha *et al*, 2007)

2.3 1. Effect of soil moisture on growth

In rainy season, increase in vine length is observed in long pepper plants. This may be due to increased supply of soil moisture during the rainy season (Sheela, 1996) Long pepper plants provided with highest amount of water resulted in taller plants, highest leaf area and leaf area index compared to minimal irrigation (Manjunatha *et al*, 2007) Vine length, leaf number and number of spikes were increased by scheduling irrigation at CPE 15 mm along with FYM @ 20 t ha^{-1} (Anilkumar *et al*, 2009) Improvement in plant height, leaf stem ratio and dry matter accumulation of mint plants is possible by increasing the level of irrigation from 60 per cent PE to 100 per cent PE (Behera *et al*, 2015)

2.3.2. Effect of soil moisture on yield parameters

Sheela (1996) observed that water stress during summer months can negatively influence vine length and number of branches in long pepper. This will result in reduced yield. A linear increase in plant height was observed in *Capsicum annum* in relation to increase in soil moisture content. Number of flowers opened was also maximum in 100 per cent moisture and less was recorded by 25 per cent moisture content. Number and weight of marketable fruits also followed this trend. Floral abortion was higher in plants supplied with 25 per cent moisture and was less in plants supplied with 100 per cent moisture (Abayomi *et al.*, 2012).

2.3.3. Effect of soil moisture on yield

Soil moisture has a significant role in improving spike yield. Singh *et al.* (2002) found patchouli plants receiving irrigation at 1.0 IW/CPE ratio produced higher fresh herbage and oil yield over the plants receiving irrigation at 0.8 IW/CPE ratio. The favourable moisture content obtained throughout the life cycle may be the reason for the improved herbage and oil yield. Irrigating aswagandha plants at 80 per cent PE resulted in higher root yield compared to 60 and 100 per cent PE (Behera *et al.*, 2012). The green herb, drug herb and drug leaves yield were higher in purple basil which are irrigated with higher amount of water compared to plants receiving lower amount of water (Ekren *et al.*, 2012).

2.3.4. Effect of soil moisture on quality parameters

In long pepper maximum protein content, protein yield and piperine yield were observed in irrigation at 100 CPE. But irrigation levels didn't have any influence on piperine content (Manjunatha *et al.*, 2007). Irrigation levels can influence quality parameters of medicinal crops. The essential oil content of purple basil was higher in plants receiving lower irrigation than which were receiving higher irrigation (Ekren *et al*, 2012)

2 4 METHODS OF IRRIGATION

Micro irrigation methods can save irrigation water to a large extent In corn, sub surface drip irrigation can save about 20 to 25 per cent water in deep silt loam soils under semi arid condition In drip irrigation system, only 15 to 60 per cent of the soil surface is generally wetted Earlier, fertigation was practiced only in widely spaced crops Economic and ecological considerations extended the implementation of fertigation system in closely spaced crops as well Several experiments have shown positive responses in most of the crops to high frequency drip irrigation Adopting drip irrigation in banana can reduce water consumption to 70 per cent than basin method of irrigation (Shimi, 2014)

2.4.1. Effect of method of irrigation on growth

Over furrow irrigation, drip irrigation can increase the leaf area index and total dry matter production in tomato (Hebbar *et al* 2004) Bansod (2007) found that an increase in plant height of about 24 64 per cent is possible in cauliflower by adopting micro sprinkler irrigation over furrow irrigation Maximum number of leaves, curd diameter, curd weight and curd volume were also higher in microsprinkler irrigation over furrow irrigation In garlic, highest plant height was obtained in drip irrigated plants (100 CPE) than that of sprinkler irrigated plants (100 CPE) (Sankar *et al*, 2008) Irrigation through micro sprinkler and bubbler along with fertigation can increase the canopy spread in litchi than that of conventionally irrigated plants (Singh *et al*, 2010)

2.4.2. Effect of method of irrigation on yield parameters

Drip and sprinkler irrigation have a positive effect in polar and equatorial diameter of bulbs in garlic Improved nutrient availability in the root zone will increase the translocation of photosynthates in to storage organ thereby diameter of bulbs got increased (Sankar *et al*, 2008)

2.4 3. Effect of method of irrigation on yield

Sampathkumar *et al* (2006) observed that increase in seed cotton yield under drip irrigation was 24, 35, 45 and 53 per cent over-all furrow, skip furrow, alternate furrow and check basin methods respectively Kumar *et al* (2009) observed that on comparison with furrow irrigation in potato, microsprinkler irrigation and drip irrigation can achieve 31 80 and 28 46 per cent higher yield respectively Over conventional surface irrigation and fertilizer application, microsprinkler fertigation once in 2 days with 75 per cent NPK dose can achieve higher yield income, water and fertilizer saving benefits in radish (Fanish *et al*, 2011) Behera *et al* (2012) observed that 8 8 per cent more root yield and 9 per cent more seed yield can be achieved in drip irrigated aswagandha than surface irrigated ones Adopting microsprinkler irrigation in tomato can result in higher yield compared to drip irrigated ones But highest water use efficiency is obtained by adopting drip irrigation over microsprinkler Mint plants can achieve a 16 per cent increment in yield by the adoption of drip fertigation (Behera *et al* 2015)

2.4.4. Effect of method of irrigation on quality parameters

Drip irrigation has a positive effect on alkaloid content In ashwagandha plants drip irrigation can increase the alkaloid content to 0 05 per cent over surface method of irrigation Good quality roots can also be obtained by adopting drip irrigation practices in ashwagandha (Behera *et al*, 2015)

2 5 SOURCE EFFICACY OF NUTRIENTS

Fertilizing long pepper vines with organic manures @ 20 t ha^{-1} had a positive response on plant height (Sheela, 1996) Growth and yield will be maximum in long pepper when it is supplied with higher manurial doses since it is a heavy feeder of nutrients Addition of organic manures have positive effects on growth and production in long pepper Crude extract per cent was also improved by the application of FYM (Anilkumar *et al*, 2009)

2.5.1. Effect of NPK on growth

Fertilizing long pepper plants with 30 30 60 N P_2O5 K_2O kg ha^{-1} yr^{-1} resulted in maximum plant height, number of branches, number of leaves and dry matter production (Ayisha, 1997) Highest vine length was observed in long pepper plants when supplied with 30 30 60 N P_2O5 K_2O kg ha^{-1} yr^{-1} followed by 60 60 120 N P_2O5 K_2O kg ha^{-1} yr^{-1} (Bijilykrishnan, 2003) Manjunatha *et al* (2007) observed higher plant height, number of branches, LAI and LAD in long pepper with the application of 30 t FYM + 100 40 140 kg N P_2O5 K_2O

2.5.2. Effect of NPK on yield parameters

Highest number of spikes and branches were produced by long pepper plants when they are supplied with 30 30 60 kg N P_2O_5 K_2O ha^{-1} along with 20 tonnes organic manure (Sheela, 1996) Ayisha (1997) observed highest number of spikes per plant, fresh and dry spike yield when long pepper plants were supplied with 30 30 60 kg N P_2O5 K_2O ha^{-1}

2 5 3. Effect of NPK on yield

Sheela (1996) observed that fertilizing long pepper plants with 30 30 60 kg N P_2O_5 K_2O ha^{-1} along with 20 tonnes organic manure resulted in the highest number of spikes Application of 200 kg nitrogen to patchouli plants produced higher herbage and oil yield compared to plants which were receiving 0 to 100 kg N per hectare (Singh *et al*, 2002) Application of vermicompost @ 6 25 t ha^{-1} yr^{-1}, NPK 30 30 60 kg ha^{-1} yr^{-1} and combined application of Azospirillum, Fluorescent pseudomonas and AMF were found to be favourable for improving spike yield and alkaloid content in long pepper (Bijilykrishnan, 2003) Combining 30 30 60 kg N P K ha^{-1} and bio inoculants including Azospirillum, pseudomonas and AMF resulted in maximum yield in long pepper at 7 and 11 MAP (Anilkumar *et al*, 2009) When water soluble NPK fertilizer (19 19 19) was applied to black pepper plants in different concentrations, maximum berry yield was obtained from plants which were receiving 1 per cent spray followed by 1 5 per cent spray (Krishnamurthy *et al*, 2013)

2.5.4. Effect of NPK on quality parameters

Highest protein content, protein yield and piperine content were recorded in long pepper plants receiving 100 40 140 kg N P_2O_5 K_2O ha^{-1} + 30 t FYM (Manjunatha *et al*, 2007) Oleoresin content was highest in black pepper plants receiving 0 5 per cent NPK (19 19 19) spray (Krishnamurthy *et al* 2013)

2.5.5. Effect of secondary and micro nutrients on growth

Boron is an important element which is involved in flowering, fertilization, hormonal metabolism and translocation of sugars (Mallick and Sawhney, 1998) Foliar spay of magnesium has increased the pseudostem length in banana compared to others which are not receiving any foliar sprays (Mostafa *et al*, 2007) Application of magnesium and micronutrients had increased the plant height in palmarosa (Rao and Rajput 2011) Magnesium plays an important role in transport of photoassimilates in to roots shoot tips and seeds Proper magnesium nutrition is essential for obtaining better nitrogen use efficiency and accumulation of nitrogen in grain In crops, heat and radiation related losses can be reduced by proper magnesium fertilization (Cakmak, 2013)

2.5.6. Effect of secondary and micro nutrients on yield parameters

Foliar application of boron at 50, 100, 150 200, 250 and 300 ppm improved the plant height, number of branches, number of fruits per plant and total tomato yield (Babu, 2002) Number of fingers per bunch was higher in banana when it was supplied with magnesium in chelated form (Mostafa *et al*, 2007) In palmarosa, number of tillers per plant and total biomass per hectare were increased by the foliar application of Mg and micronutrients (Rao and Rajput, 2011)

2.5.7. Effect of secondary and micro nutrients on yield

In banana, bunch weight was higher when supplied with Mg in chelated form along with foliar spray (Mostafa *et al* 2007) Maximum number of spikes and yield were observed in black pepper plants supplied with 50 per cent recommended dose of nitrogen along with magnesium (Thankamani *et al*, 2011)

2.5.8. Effect of secondary and micro nutrients on quality parameters

Magnesium applied in the form of both chelate and sulphate provided higher TSS and total sugars in banana (Mostafa *et al* 2007) Foliar feeding of magnesium and micro nutrients including boron increased per hectare essential oil yield in palmarosa Geraniol percentage was also increased by application of magnesium and boron in first harvest (Rao and Rajput, 2011)

2.5.9. Effect of vermiwash on growth

Highest per cent increase in biomass production, higher nodule number and higher nodule weight were obtained in cowpea due to the foliar application of coconut leaf vermiwash at 1 20 dilution (Gopal *et al* 2010) Vermiwash is rich in nutrients and plant hormones which enhances the growth of plants (Rekha *et al*, 2013) More *et al* (2013) reported that in maize application of vermiwash in three sprays produced higher plant height, dry matter production and LAI compared to no vermiwash spray

2.5.10. Effect of vermiwash on yield parameters

In maize, highest cob weight and fresh biomass yield is observed due to the application vermiwash in 1 5 dilution (Gopal *et al*, 2010) Application of vermiwash as three sprays reduced period for 50 per cent tasseling and silking compared to no vermiwash spray (More *et al*, 2013) Ayyobi *et al* (2014) found more number of leaves, number of pods per plants and lateral branches in dwarf French bean when they were supplied with vermiwash compared to vermicompost leachate Maximum root diameter, length and weight were recorded in radish plants receiving vermiwash spray (1 4) compared to control (Jadhav *et al*, 2015)

2.5.11. Effect of vermiwash on yield

Number of flowers produced in marigold was higher due to application of vermiwash (Sivasubramanian and Ganeshkumar, 2004) Vermiwash applied at 1 5 (v/v) and 1 10 (v/v) provided higher yield in spinach and onion respectively Slow nutrient release along with plant hormones like gibberellin, cytokinin and auxin present in these manures resulted in improved yield in crops (Ansari, 2008) Application of vermicompost improved spike production in long pepper at 11 MAP compared to FYM application alone (Anilkumar *et al*, 2009) Vermiwash in higher dilutions resulted in higher cob yield in maize In bhendi, an increase of 33 per cent yield was observed due to the application of coconut leaf vermiwash in 1 5 dilution (Gopal *et al*, 2010) Foliar spray of vermiwash at 20 per cent concentration improved vegetative and yield attributes in chilli and okra in acidic soil (Meghavansi *et al*, 2012) Yield components and yield were also higher in radish plants receiving vermiwash spray at 1 4 (water vermiwash) dilution than other lower dilutions (Jadhav *et al* 2015)

2.5.12. Effect of vermiwash on quality parameters

Zaller (2006) observed that quality improvement in tomato is possible by the foliar application of vermicompost leachate Protein and fat content in okra were also higher when they were treated with vermiwash and vermicompost (Ansari and Kumar, 2010) Siddappa and Hegde (2011) observed higher leaf thickness and essential oil content in curry leaf due to foliar spray of vermiwash

2.5 13 Effect of fermented plant juice on growth

Foliar spray of liquid organic manures have significant effect on crop growth and yield of various crops Foliar spray of liquid organic manures at flowering and 15 days after flowering can positively influence growth in chick pea (Patil *et al*, 2012)

2.5.15. Effect of fermented plant juice on yield parameters

Udabal *et al* (2014) reported that application of liquid organic manures to sunflower plants resulted in maximum capitulum diameter, seed filling percentage and seed yield Corn plants receiving bio digester liquid spray @ 10 per cent recorded higher cob length and cob girth (Waghmode *et al*, 2015)

2.5.16 Effect of fermented plant juice on yield

Yield of brinjal plants was appreciably improved by the application of organics Sole application of cow urine fermented botanicals or in combination with panchagavya was found to be superior for improving fruit yield Plants receiving cow urine fermented Hyptis leaves + panchagavya resulted in maximum fruit yield (Shailaja *et al*, 2011) Waghmode *et al* (2015) reported that application of bio digestor liquid @ 10 per cent recorded maximum cob yield in maize

2.5.17. Effect of fermented plant juice on quality parameters

Shailaja *et al* (2011) observed an increase in chlorophyll content of brinjal with organics spray Total chlorophyll content increased from 3 rd spray to 6th spray (from 0 864 to 1 669 and from 1 216 to 2 009 mg per gram of fresh tissue respectively) After 3rd spray, cow urine fermented Hyptis leaves resulted in highest chlorophyll content followed by cow urine fermented lantana leaves and cow urine fermented neem leaves After 6th spray, cow urine fermented neem leaves and panchagavya resulted in appreciable chlorophyll content followed by cow urine fermented lantana leaves

2 5.18. Effect of cow urine on growth

In wheat, seed treatment with cow urine resulted in maximum plant height, number of green leaves, dry matter production, leaf area index and leaf area duration compared to control (without seed treatment) (Sivamurthy and Patil, 2006) Presence of hormones like auxin in cow urine stimulates the growth of plants (Oliveira *et al*, 2009) Different potassium levels along with foliar spray of cow urine increased plant height, dry matter production and yield in mung bean Plant height, dry matter production and grain yield of green gram were increased by different potash levels and cow urine spray (Patil and Gunjal, 2011) Deotale *et al* (2011) observed the maximum plant height and leaf area in soybean plants which were receiving 6 per cent foliar spray of cow urine

2.5.20. Effect of cow urine on yield parameters

Ingale *et al* (2007) observed that black gram plants receiving 6 per cent cow urine + 50 ppm NAA spray recorded the highest number of pods per plant, 100 seed weight and seed yield Same results were also obtained in soybean by Deotale *et al* (2011) Combined application of nitrogen fertilizers along with cow urine improved tiller production in rice over control (Singh *et al*, 2014) In corn, applying RDF + 10 per cent cow urine significantly improved the cob girth and cob length of maize (Waghmode *et al*, 2015)

2.5.21. Effect of cow urine on yield

Foliar spray of cow urine resulted in higher grain yield over water spray in mung bean (Patil and Gunjal, 2011) Sobhana (2014) reported that cow urine spray has a positive effect on the yield of jasmine plants Yield of jasmine plants had improved by the application of cow urine at 15 times dilution Nitrogen fertilizers along with cow urine recorded higher yield in rice over control (Singh *et al*, 2014) Application of cow urine @ 10 per cent spray recorded appreciable yield in maize (Waghmode *et al* 2015)

2.5.22. Effect of cow urine on quality parameters

Leaf nitrogen content of soybean was improved by application of 6 per cent cow urine + 2 per cent DAP or urea spray (Thakre *et al*, 2006) In black gram maximum protein, chlorophyll and leaf nitrogen content were observed with 6 per cent cow urine + 50 ppm NAA (Ingale *et al*, 2007) Conjunctive use of cow urine and application of nitrogen alone improved nitrogen content of straw and grain in rice (Singh *et al*, 2014) Protein content of maize plants can be significantly improved by the application of cow urine @ 10 per cent This may be due to the presence of uric acid and plant growth substances in cow urine (Waghmode *et al*, 2015)

2.5.23. Effect of sequential application on growth

Growth and yield of plants can be regulated by adequate supply of nutrients Need based application of nutrients is the best approach for obtaining appreciable yield in crops So split and rotational application of nutrients can be adopted for improving the growth and yield of crops Improved uptake of nutrients can be achieved by frequent application of fertilizers through drip system This may be due to the continuous replenishment of nutrients in the depletion zone near the roots (Sathya *et al*, 2008) Feleafel and Mirdad (2013) reported that brinjal plants can achieve increase in plant height, number of branches and leaves, leaf area and dry weight per plant by increasing the number of splits and doses of fertilizers

2.5.24. Effect of sequential application on yield parameters

Fertigating chilli plants at two days interval with recommended dose of fertilizers increased number of fruits per plant, weight of fruit per plant and green chilli yield (Tumbare and Nikam, 2004) Daily drip cum sub surface fertigated chilli plants produced higher fruit length, fruit girth, number of flowers, fruits per plant and mean fruit weight compared to weekly and biweekly fertigated plants (Prabhakara *et al*, 2010)

2.5.25. Effect of sequential application on spike yield

Buckerfield *et al* (1999) reported that 7 3 per cent increase in radish yield is possible by the weekly application of vermiwash Fertigation at 75 per cent NPK at 10 days interval resulted in highest yield followed by 75 per cent NPK at 20 days frequency in arecanut Daily fertigated onion plants registered the maximum yield followed by alternate day fertigation and weekly fertigation Monthly fertigated onion plants produced the lowest yield (Patel and Rajput, 2005) Fertigating nitrogen in 8 to 10 split doses and scheduling irrigation at 100 per cent ET_0 recorded maximum fruit yield in tomato (Bahadur *et al*, 2006) A hundred per cent yield increment can be achieved by supplying 75 per cent NPK at 10 days interval over control which are receiving drip irrigation and 100 per cent NPK as soil application (Bhatt and Sujatha, 2009)

2.5.26. Effect of sequential application on quality parameters

NPK content of leaves and fruits of eggplant can be increased by increasing the fertigation frequency by three doses of fertilizers per week compared to biweekly application of one dose (Feleafel and Mirdad, 2013) Total soluble solids and ascorbic acid content of chilli was significantly improved by daily subsurface fertigation over weekly or biweekly fertigation (Prabhakara *et al*, 2010)

2.5.27. Effect of soil and foliar application on growth

Siddiqi *et al* (2008) observed that shoot length, leaf number, leaf area index and fresh weight of mustard plants were improved by soil + foliar application of nutrients Anburani and Gayathri (2010) found that application of press mud @ 25 t ha^{-1} along with RDF and 0 2 per cent humic acid recorded the highest vine length, number of leaves, leaf area, and internodal length in gherkin For obtaining better crop height in tomato soil application of boron was found to be more effective than foliar application (Sathya *et al* 2010)

2.5.28. Effect of soil and foliar application on yield parameters

Boron applied in the form of foliar spray produced maximum number of pods per plant in bean (Harmankaya *et al*, 2008) Lentil plants supplied with NPK in both foliar and soil application resulted in maximum pod weight, number of pods per plant and thousand grain weight (Hamayun *et al* 2011)

2.5.29. Effect of soil and foliar application on yield

In tomato, application of fertilizers half through soil and half through foliar resulted in 12 1 and 8 9 per cent yield increment over full soil application and one fourth soil application plus three fourth foliar application respectively during first year During second year yield increment was 11 8 and 17 4 per cent for the same method (Chaudhuri and De, 1975) Yield and size of fruits in tomato were found to be superior in foliar application compared to soil application (Dipti *et al*, 2008) Foliar application of boron to bean plants resulted in 20 per cent higher yield compared to soil application of boron (Harmankaya *et al* 2008) Foliar spray of 19 19 19 NPK fertilizer reduced the alternate bearing activity of black pepper 1 per cent spray of this water soluble fertilizer increased the yield by 29 per cent compared to plants receiving water spray (Krishnamurthy *et al*, 2013)

2.5.30. Effect of soil and foliar application on quality parameters

Soil + foliar application of N and P resulted in the increase of linoleic, linolenic and erucic acid content in mustard Higher level of enzymatic activity is observed in foliar fertilized plants compared to soil fertilized ones It may be due to the readily available nutrients at the site of action (Siddiqi *et al*, 2008) Sathya *et al* (2013) found foliar application of boron to tomato plants improved the soil boron status

2 6 MICROBIAL INOCULANTS

Plant growth promoting rhizobacteria and other microbial inoculants in non-leguminous crops promote the growth by different mechanisms Utilization of microbial inoculants in intensive agriculture can maintain soil quality and sustainability

2.6.1. Effect of PGPR on growth

Under organic growing conditions, Bacillus spp have a capacity to increase the growth, yield and nutrition of raspberry (Orhan *et al*, 2006) Maximum sprouting percentage, leaf number, plant height, root number and dry matter production were observed in long pepper due to the combined application of pseudomonas, PSB and AMF (Anilkumar *et al*, 2009) Plant growth promoting rhizobacteria is capable of producing different phytohormones, organic acids and siderophore which improve growth of plants Apart from this, they have a capacity to fix nitrogen, solubilizing phosphorous and produce plant growth regulators that can positively influence plant growth (Prathap and Kumari, 2015)

2.6.2. Effect of PGPR on yield parameters

Root length, rooting performance and dry matter content of mint were improved by inoculation with *Bacillus megaterium* (Kaymak *et al*, 2008) In strawberry, number of runners per plant and ratio of usable runner per plant were significantly higher due to foliar + root application of PGPR (Pirlak and Kose, 2010) Akbari *et al* (2011) observed that head diameter and 1000 grain weight were higher in PGPR treated sunflower plants compared to control plants

2.6.3. Effect of PGPR on yield

Some of the PGPR are capable of converting the insoluble phosphorous form in to soluble form thereby increases uptake of phosphorus This will lead to increased yield of crops (Rodriguez *et al*, 2006) Anilkumar *et al* (2009) observed the beneficial effects of integrating Azospirillum, Pseudomonas and AMF for higher spike production in long pepper PGPR inoculation in sunflower resulted increase in yield of an 8 per cent compared to un-inoculated plants (Akbari *et al* 2011)

2.6.4. Effect of PGPR on quality parameters

Amount of palmitic acid, total nitrogen and protein content were higher in *Salicornia bigelovii* when inoculated with PGPR (Bashan *et al*, 2000) In sunflower, protein and oil content were increased by inoculation with PGPR over control (Akbari *et al*, 2011) Growth and alkaloid content in *Withania somnifera* were improved by the application of plant growth promoting rhizobacteria (Rajasekar and Elango, 2011) Yolcu *et al* (2011) reported that crude protein content in rye grass was increased due to the application of PGPR along with manures N, P, K, S, Fe, Mn and Zn content in wheat were increased when they were inoculated with PGPR (Turan *et al* 2012) Single or combined inoculation of rhizobacteria in different combinations had increased Aloin content in *Aloe vera* (Ashok and Kalaiarasu, 2014) Seed inoculation of PGPR + PSB + Rhizobium improved the protein content in pigeon pea (Zadode *et al* 2014)

2.6.5. Effect of pseudomonas on growth

Pseudomonas fluorescence has a capacity to improve plant growth and nutrient uptake by producing certain growth promoting substances and secondary metabolites (Burr *et al*, 1978) Yield and growth of chickpea plants were stimulated by the application of fluorescent pseudomonas in the form of microbial fertilizer (Mehnaz *et al* 2009) It is capable of producing antibiotics, phytohormones, volatile compounds, indole-3-acetic acid and siderophore which promote the growth and resistance mechanism of crops (Sivasakthi *et al*, 2014) In broccoli, maximum shoot phosphorous content was recorded when it was treated alone with Pseudomonas (Tanwar *et al*, 2013) Pseudomonas is capable of directly promoting the growth of plants by producing phytohormones and solubilizing phosphorous Verma *et al* (2014) concluded that application of 100% RDF + *Pseudomonas fluorescens* + humic acid to cabbage had significantly improved the plant height Efficiency of fertilizer, solubilisation and transport of nutrients were improved by application of *Pseudomonas fluorescens* along with humic acid which improved the plant height

2.6.6. Effect of pseudomonas on yield parameters

Inoculation of pseudomonas to soybean plants resulted in the higher number of pods per plant Combined inoculation of *Pseudomonas fluorescence* and *Pseudomonas putida* significantly increased the number of pods on maim stem, number of pods per plant and number of seeds per pod (Yasari and Alasthi, 2013)

2.6.7. Effect of pseudomonas on yield

Johri (2001) found that increase in yield in legumes is possible when they are treated with pseudomonas strains Ahmad *et al* (2013) observed inoculating Pseudomonas containing ACC- deaminase to mung bean improved the pod fresh yield to an extent of 9-27 per cent over uninoculated control

2 6.8. Effect of pseudomonas on quality parameters

Protein and carbohydrate content of cabbage plants were improved by the application of fluorescent pseudomonas and humic acid Microbes have a capacity to improve the nutrient uptake of plants there by enhanced the sugar transport Inoculation of fluorescent pseudomonas has increased the vitamin C content of cabbage plants to 15 72 per cent compared to 100 per cent RDF (Verma, 2014)

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The experiment entitled 'source efficacy of nutrients and fertigation in long pepper (*Piper longum* L.)' was carried out at the Instructional farm attached to the College of Agriculture, Padannakkad to study the effect of micro irrigation and fertigation with water soluble fertilizers, liquid organic manures and plant growth promoting rhizobacteria on the growth, productivity, quality and economics of intercropped long pepper under poly cum shade house in coconut garden. Experiment was conducted during the period from 2014 to 2016.

The materials used and methods followed for conducting the experiment are furnished in this chapter.

3.1 MATERIALS

3.1.1. 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 longitudes at an altitude less than 20 m above MSL.

3.1.2. Cropping history

The experiment was conducted inside a poly cum shade house erected in the interspaces of a middle aged coconut garden. The area was lying fallow before the commencement of the experiment. Soil of experimental site is sandy (Hosdurg series). The mechanical and chemical composition of soil are presented in Tables 1 and 2 respectively.

3 1 3. Crop and variety

Long pepper is a slender creeping dioecious perennial Erect branches raising from the main stem bears fruits Fruits are born on leaf axil Fruit is a spike which is creamy white at immature stage which gradually turns in to dark green on maturity Mature unripe female fruit is the economic part 'Viswam' variety released from Kerala Agricultural University was used for the experiment

3.1.4. Weather parameters

Weather parameters observed during 01 01 2015 to 31 03 2016 are presented in Appendix 1 and graphically represented in Figure 1 Abstract of these parameters are given in Table 3

Table 1 Mechanical composition and moisture characteristics of soil

Particulars	Content	Method used
1 Mechanical composition (%)		
Coarse sand, (%)	30 28	Bouyoucos hydrometer
Fine sand, (%)	57 65	method
Silt, (%)	7 5	(Bouyoucos, 1962)
Clay, (%)	4 57	
2 Soil moisture characteristics		
Particle density, g cc ^{1}	2 16	Pycnometer method
Bulk density, g cc ^{1}	1 34	(Black, 1965)
Maximum water holding capacity, % (w/w)	18 2	Core method (Gupta and
Porosity, % (v/v)	47	Dakshinamoorthi, 1980)
Field capacity, %(w/w)	11 74	
Permanent wilting point, % (w/w)	4 98	

Table 2 Chemical properties of soil

Particulars	Content	Method
Organic carbon, %	0 30	Walkley and Black titration method (Jackson, 1973)
Organic matter, %	0 51	
Available nitrogen, kg ha ^{1}	239 39	Alkaline $KMnO_4$ method (Subbiah and Asija,1956)
Available phosphorus, kg ha ^{1}	25 15	Bray's colorimetric method (Jackson, 1973)
Available potassium, kg ha ^{1}	65 26	Ammonium acetate method (Jackson, 1973)
Available magnesium, kg ha ^{1}	31 66	Atomic absorption spectroscopy (Jackson,1958)
Available boron, kg ha ^{1}	2 47	Photoelectric colorimetry (Bingham, 1982)
Soil reaction	5 6	pH meter with glass electrode (Jackson, 1973)

Table 3 Abstract of weather data during experimental period, January 2015 to March 2016

Weather parameters	Range	Mean
Maximum temperature (^{0}C)	29 96 – 33 61	31 85
Minimum temperature (^{0}C)	19 33 – 24 57	22 54
Relative humidity (%)	73 79 – 88 08	79 80
Monthly evaporation (mm)	1 96 – 5 34	3 55
Total rainfall (mm)	2022 93	-

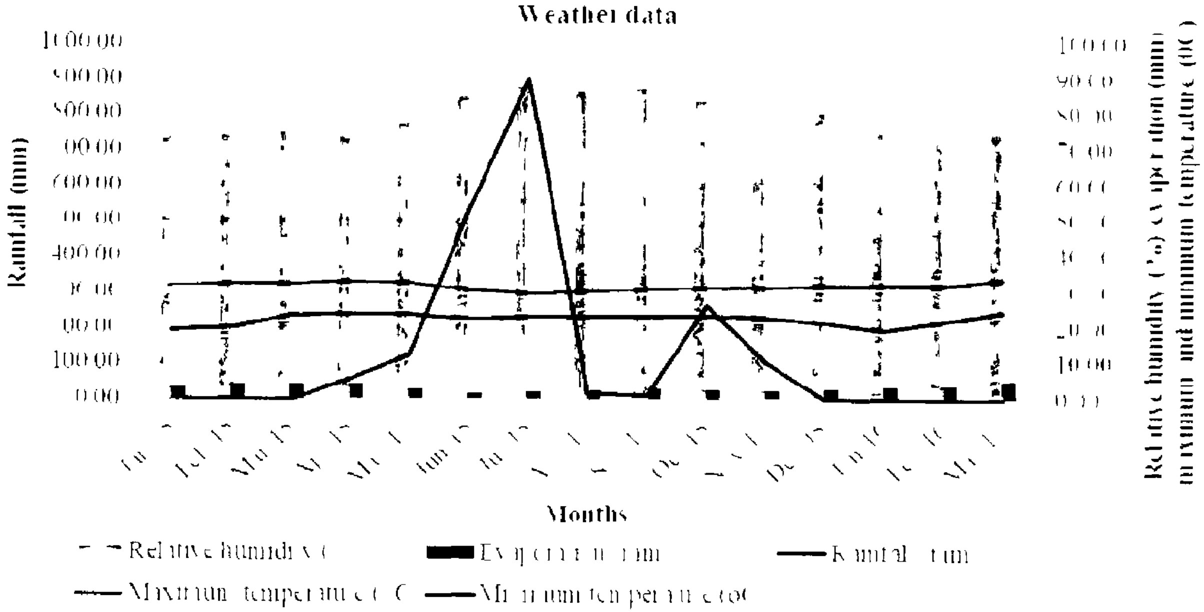


Fig 1 Weather data during the crop period (01 01 2015 to 31 03 2016)

3 2 METHODS

3.2.1. Design and Layout

Design Factorial RBD

Treatments 12+2

Replication 2

Plot size 2 5 m x 2 m

Lay out of experimental field is given in Fig 2

3.2.2. Treatments

Factor A Methods of irrigation (2)

M_1 Microsprinkler irrigation

M_2 Drip irrigation

Factor B Fertigation (6)

F_1 Water soluble NPK fertilizer

F_2 Liquid organic manures

F_3 Water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas

F_4 Liquid organic manures + PGPR Mix – I + Fluorescent pseudomonas

F_5 Water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas + Mg + B

F_6 Liquid organic manures + PGPR Mix– I + Fluorescent pseudomonas + Mg + B

Controls

CF Intercropping in coconut garden as per POP, KAU (foliar application)

CS Intercropping in coconut garden as per POP, KAU (soil application)

3.2.3. Treatment combinations (2 x 6) + 2

Treatment combinations are presented in Table 4

Table 4 Treatment combinations

No	Representation of treatment	Treatment combinations
1	T_1	M_1F_1 - Microsprinkler irrigation + Water soluble NPK fertilizer
2	T_2	M_1F_2 - Microsprinkler irrigation + Liquid organic manures
3	T_3	M_1F_3 - Microsprinkler irrigation + Water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas
4	T_4	M_1F_4 - Microsprinkler irrigation + Liquid organic manures + PGPR Mix– I + Fluorescent pseudomonas
5	T_5	M_1F_5 - Microsprinkler irrigation + Water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas + Magnesium + Boron
6	T_6	M_1F_6 - Microsprinkler irrigation + Liquid organic manures + PGPR Mix– I + Fluorescent pseudomonas + Magnesium + Boron
7	T_7	M_2F_1 - Drip irrigation + Water soluble NPK fertilizer
8	T_8	M_2F_2 - Drip irrigation + Liquid organic manures

9	T_9	M_2F_3 - Drip irrigation + Water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas
10	T_{10}	M_2F_4 - Drip irrigation + Liquid organic manures + PGPR Mix – I + Fluorescent pseudomonas
11	T_{11}	M_2F_5 - Drip irrigation + Water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas + Magnesium + Boron
12	T_{12}	M_2F_6 - Drip irrigation + Liquid organic manures + PGPR Mix– I + Fluorescent pseudomonas + Magnesium + Boron
Controls		
1	CF	Intercropping in coconut garden as per POP, KAU (foliar application)
2	CS	Intercropping in coconut garden as per POP, KAU (soil application)

3.2.4. Planting material production

Rooted long pepper saplings were used as the planting material 3 to 5 noded cuttings taken from healthy vines were planted in black polythene cover filled with rooting media (soil sand cowdung in the ratio 1 1 1) during October Sapling production was carried out inside a poly cum shade house Two month old saplings were planted in the main field

3.2.5. Planting

Trenches of 2 m long, 20 cm wide and 70 cm deep were taken in the field Transparent low density polyethylene sheets were spread inside each pit A mixture of FYM (20 t ha^{-1}), *Tephrosia purpurea* biomass and dried plant leaves

Fig 2. Lay out of the experimental field

T_3R_1
T_5R_1
T_1R_1
T_2R_1
T_6R_1
T_4R_1
T_1R_2
T_5R_2
T_4R_2
T_6R_2
T_3R_2
T_2R_2
T_8R_1
$T_{11}R_1$
$T_{12}R_1$
T_7R_1
$T_{10}R_1$
T_9R_1
T_8R_2
$T_{11}R_2$
$T_{12}R_2$
T_7R_2
$T_{10}R_2$
T_9R_2
C_1F
C_2S
C_2F
C_1S

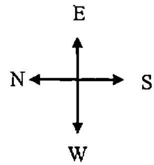
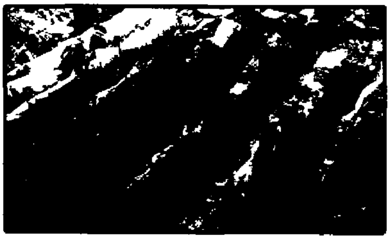
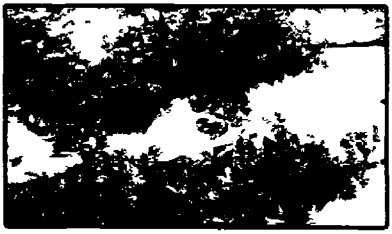


Plate 1. General view of experimental field



a. Microsite enrichment

b. Microsprinkler irrigation



c. Drip irrigation

d. Crop at bearing stage

e. Poly cum shade house

f. Matured female spikes

were applied to each pit and filled with top soil Rooted long pepper saplings were planted at a spacing of 40 x 40 cm @ one plant per hill

3.2.6. Treatment imposition

3.2.6.1. Irrigation

Microsprinkler and drip irrigation systems were laid out as per the technical programme Microsprinkler of 60 litres discharge per hour covering an area of 5 m^2 was erected at the centre of plot Dripper of 1 5 litre discharge per hour was laid out at a spacing of 40 cm between each drip

3.2.6.2. Fertigation

Fertigation was carried out at 10 days interval A bypass fertigation tank with a screen filter system was used for fertigation All treatments were imposed through the fertigation system attached to microsprinklers (foliar application) and drippers (soil application) Rotational application of liquid organic manures including vermiwash, cow urine (desi cow) and fermented plant juice were carried out @ 1 10 (v/v) dilution

3.2.6.1. Fertilizers

Water soluble NPK fertilizers were applied @ 30 30 60 kg ha^{-1} yr^{-1} Magnesium was applied as magnesium sulphate @ 40 kg ha^{-1} and boron as borax @ 5 kg ha^{-1}

3.2.6.2. Vermiwash

Preparation of vermiwash was carried out as per the protocol standardised by KAU (KAU, 2011)

3.2.6.3. Fermented plant juice

Fermented plant juice used for fertigation was prepared as follows Tender parts of Singapore daisy (*Spagnaticola trilobata*) was taken and chopped in to small pieces Equal amount of powdered brown sugar (weight basis) was added to this Mixture was transferred to a plastic vessel and completely filled with water Mouth of the vessel was sealed using a towel and tied The vessel was kept as such without any disturbance for one week and allowed for complete fermentation After one week the mixture was strained using a cloth and applied in the field

3.2.6.4. Cow urine

Urine of a desi cow was used for fertigating plants

3.2.6.5. Microbial inoculants

PGPR mix– I and Fluorescent pseudomonas developed by KAU were applied rotationally in the plots @ 2 per cent

3.2.7. Post planting care

Planted saplings well established in the field Weeding was carried out at monthly intervals Incidence of spike borer and tea mosquito bug were observed and controlled through spraying insecticide Acephate Imposition of treatments were carried out as per the technical programme

3.2.8. Harvesting

Spikes were harvested at bi monthly interval from 7 MAP to 15 MAP and all together five harvests were made

3.2.6. Irrigation scheduling

Table 5 Details of irrigation given during experimental period

Treatments	No of irrigations	Irrigation requirement (litre / plot)	Pretreatment irrigation (litre / plot)	Effective rainfall (litre / plot)	Total water requirement (litre / plot)
M_1F_1	69	4830	70	0	4830
M_1F_2	69	4830	70	0	4830
M_1F_3	69	4830	70	0	4830
M_1F_4	69	4830	70	0	4830
M_1F_5	69	4830	70	0	4830
M_1F_6	69	4830	70	0	4830
M_2F_1	69	4830	70	0	4830
M_2F_2	69	4830	70	0	4830
M_2F_3	69	4830	70	0	4830
M_2F_4	69	4830	70	0	4830
M_2F_5	69	4830	70	0	4830
M_2F_6	69	4830	70	0	4830
CF	69	3825	70	1005	4830
CS	69	3825	70	1005	4830

3 3 OBSERVATIONS

Observations were taken from five plants per plot and the mean worked out

3.3 1. Morphological characters

Morphological characters were recorded at bi monthly intervals from 7 MAP to 15 MAP synchronising with spike harvest Observations were taken and mean worked out

3.3.1.1. Vine length

Length of the longest vine was measured from base of the plant to tip and expressed in cm

3.3.1.2. Number of leaves

Total number of leaves were counted and recorded

3.3.1.3. Number of branches

Total number of branches per vine was counted and recorded

3.3.1.4. Leaf area

Leaf area was measured using a leaf area meter

3.3.1.5. Leaf area index

Leaf area index was calculated using the following formula

$$\text{Leaf area index} = \frac{\text{Leaf area}}{\text{Land area}}$$

3.3.2. Root parameters

3.3.2.1. Root number

Total number of roots per plant was counted and mean worked out

3.3.2.2. Root length

Length of longest root was measured using a scale and expressed in cm

3.3.2.3. Root weight

Dry weight of roots recorded after washing and drying in hot air oven and expressed in grams

3.3.2.4. Root spread

Root spread was measured by graph paper method and expressed in cm

3 3.3. Physiological parameters

3.3.3.1. Relative leaf water content

The method proposed by Weatherly (1950) which was later modified by Slatyer and Barrs (1965) was used to determine relative leaf water content and expressed in percentage

$$RLWC = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

3.3.3.2. Leaf temperature

Leaf temperature was measured using a steady state porometer and expressed in ^0C

3.3.3.3. Stomatal conductance

Stomatal conductance was measured using a steady state porometer and expressed in CO_2 mmol/m^{2}s

3.3.3.4. Photosynthetically Active Radiation (PAR)

PAR was measured using Lightscout quantum light 3 sensor bar and expressed in W m^{-2}

3.3.3.5. Total solar radiation

Total solar radiation was measured using silicon pyranometer and expressed in W m^{-2}

3.3.3.6. Chlorophyll content

Chlorophyll reading was taken using SPAD chlorophyll meter at bi monthly interval and expressed as SPAD chlorophyll reading

3.3.4 Total dry matter production

Plants were uprooted at bi monthly interval and dried Mean weight was taken and expressed in grams

3.3 5. Biochemical parameters

3.3.5.1. Total alkaloids

Crude alkaloid extract from dried spikes was determined using the Soxhlet extraction method (Harbone, 1973)

Well dried spikes were made in to fine powder and exactly five grams of sample weighed and transferred in to a filter paper to hold the sample The sample packet was then dropped in to the extraction tube of soxhlet apparatus A previously weighed soxhlet apparatus connected to the soxhlet flask and 100 ml of solvent was poured through extraction tube in to the flask The top of flask was attached to a condenser Extraction was carried out at 80^0C on a water bath Solvent (methanol) got continuously vaporized and allowed to condense and collected inside the extraction tube This cycling repeated up to which when the solvent inside extraction tube turned colourless The extraction tube was dismantled and sample removed from the extraction tube The solvent in the soxhlet flask was evaporated on a water bath After complete evaporation of solvent from the soxhlet flask, weight of the flask along with residue was recorded and alkaloid estimated using the following formula

Weight of residue (g) = Weight of soxhlet flask along with residue (g) – Weight of empty soxhlet flask (g)

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

3.3.6. Microbiological studies

3.3.6.1. Population of PSM

Population of phosphate solubilizing microorganisms were estimated using Pikovskaya's agar medium 10^3, 10^4 and 10^5 dilutions were used for analysis

3.3.7. Yield and yield attributes

3.3.7.1. Number of spikes

Harvestable number of spikes per vine were counted at bimonthly intervals from 7 MAP onwards and the mean worked out

3.3.7.2. Fresh spike yield

Matured unripend spikes were harvested at bimonthly intervals from 7 MAP and weight recorded

3.3.7.3. Dried spike yield

Harvested spikes were shade dried and weight recorded at bimonthly intervals from 7 MAP

3.3.8. Soil moisture studies

Measurement of soil moisture at repeated intervals was carried out using soil moisture meter Observations were taken 15 cm away from the base of the plant at a depth of 10 cm

3.3.8.1. Consumptive use (Cu) of water

Consumptive use of water was worked out using the formula described by Dasthane (1972)

$$Cu = \sum_{1}^{N} (Ep \times 0.6) + \sum_{1}^{n} \frac{(Ma_i - Mb_i)}{100} \times As_i \times D_i + ER$$

Where Cu, Consumptive use of water in mm

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

0 6 = A constant used for obtaining ET value from pan evaporation value for the given period of time

Ma_i = Percentage soil moisture (w/w) of the i^{th} layer of soil at the time of sampling after irrigation

Mb_i = Percentage soil moisture (w/w) of the i^{th} layer of soil at the time of sampling before irrigation

As_i = Apparent specific gravity of i^{th} layer of soil, g cc^{-1}

D_i = Depth (mm) of the i^{th} layer of soil

ER = Effective rainfall if any within the season (mm)

N = Number of soil layers

n = Number of days between irrigation and post irrigation sampling

3.3.8.2. Irrigation requirement

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

3.3.8.3. Watei use efficiency

Crop water use efficiency (CWUE) and field water use efficiency (FWUE) were worked out using the following formula and expressed in g m ^{3}

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

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

3.3.8.4. Water productivity (WP)

Water productivity was calculated using the formula suggested by Kinje *et al* (2003) and expressed in g m^{-3}

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

3.3.8.5. Crop coefficient (Kc)

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

3.3.9. Nutrient uptake studies

Plant nutrient uptake was estimated by multiplying per cent nutrient content with total dry matter production

3.3.10. Economics

3.3.10.1. Cost of cultivation

Price of each input in rupees at the time of experiment was considered for working out cost of cultivation

3.3.10.2. Gross returns

Gross returns per hectare was calculated using the price of output prevailing in market at the time of experiment

3.3.10.3 Net returns

The net returns were calculated by subtracting cost of cultivation from gross returns

3.3.10.4 Benefit cost ratio (BCR)

Benefit cost ratio was calculated using the following formula

$$BCR = \frac{\text{Gross income}}{\text{Total expenditure}}$$

3.3 11. Statistical analysis

Statıstıcal analysıs was done usıng SAS package 9 3

RESULTS

4. RESULTS

The experiment entitled 'source efficacy of nutrients and fertigation in long pepper (*Piper longum* L)' was carried out in the Instructional farm attached to the College of Agriculture, Padannakkad during 2014 to 2016 The objective of the experiment was to study the effect of micro irrigation and fertigation with water soluble fertilizers, liquid organic manures and plant growth promoting rhizobacteria on the growth, productivity, quality and economics of intercropped long pepper under poly cum shade house in coconut garden The trial carried out in factorial RBD with two replication for a period of fifteen months consisted of combinations of two methods of irrigation *viz,* M_1 microsprinkler and M_2 drip and six levels of fertigation *viz,* F_1 Water soluble NPK fertilizer, F_2 Liquid organic manures, F_3 Water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas, F_4 Liquid organic manures + PGPR Mix– I + Fluorescent pseudomonas, F_5 Water soluble NPK fertilize r+ PGPR Mix– I + Fluorescent pseudomonas + Mg + B, and F_6 Liquid organic manures + PGPR Mix– I + Fluorescent pseudomonas + Mg + B, besides two control treatments CF Intercropping in coconut garden as per POP, KAU (foliar application) and CS Intercropping in coconut garden as per POP, KAU (soil application) The results obtained are presented in the following pages

4 1 VINE LENGTH

The effect of methods of irrigation, levels of fertigation and their interactions on vine length recorded at 7, 9, 11, 13 and 15 months after planting are presented in Table 6

Methods of irrigation significantly influenced the vine length at all stages of growth and drip irrigation recorded the highest values throughout the period of experimentation The highest vine length of 109 70 cm was recorded with drip irrigation which was 17 02 per cent higher compared to microsprinkler irrigation

Table 6 Vine length (cm) as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	51 90	66 27	76 80	83 72	93 74
M_2	73 11	81 19	90 81	100 37	109 70
Fertigation					
F_1	61 95	76 92	84 25	91 17	101 62
F_2	53 02	61 70	69 90	79 22	90 62
F_3	62 25	70 47	80 50	88 70	100 85
F_4	61 15	76 40	84 75	95 25	103 80
F_5	83 95	94 32	105 9	112 35	118 95
F_6	52 75	62 57	77 52	85 60	94 50
Interaction effects					
M_1F_1	61 85	81 80	87 90	93 90	103 40
M_1F_2	50 60	59 55	67 95	73 15	84 00
M_1F_3	59 85	63 30	77 25	86 05	100 70
M_1F_4	45 95	71 65	80 60	88 05	98 40
M_1F_5	50 60	62 20	74.45	81 20	86 95
M_1F_6	42 60	59 15	72 70	80 00	89 00
M_2F_1	62 05	72 05	80 60	88 45	99 85
M_2F_2	55 45	63 85	71 85	85 30	97 25
M_2F_3	64 65	77 65	83 75	91 35	101 00
M_2F_4	76 35	81 15	88 90	102 45	109 20
M_2F_5	117 30	126 45	137 45	143 50	150 95
M_2F_6	62 90	66 00	82 35	91 20	100 00
Treatment mean	62 51	73 73	83 81	92 05	101 72
Controls					
CF	35 05	41 30	42 10	43 75	45 00
CS	46 75	60 10	61 40	63 05	55 70
Control mean	40 90	50 70	51 75	53 40	50 35
SE					
M	4 09	3 77	3 75	4 32	4 75
F	7 09	6 53	6 49	7 49	8 23
MF	10 03	9 23	9 18	10 59	11 64
CD (0 05)					
M	8 84	8 14	8 10	9 34	10 26
F	15 32	14 11	14 03	16 18	NS
MF	21 67	19 95	19 85	22 89	25 15
Treatment Vs Control	28 28	26 05	25 91	29 88	32 89
Between controls	NS	NS	NS	NS	NS

MAP Months after planting

Levels of fertigation also significantly influenced vine length at all stages of growth except at 15 MAP Fertigation with water soluble NPK fertilizer + PGPR + Mix– I + Fluorescent pseudomonas + Mg + B was found to be favourable for enhancing vine length at all stages of growth

Interaction effects of methods of irrigation and levels of fertigation also significantly influenced the vine length throughout the period of experimentation Fertigation with water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas + Mg + B through drippers significantly improved vine length At 15 MAP the greatest vine length of 150 95cm was registered by M_2F_5 which was significantly different from all other treatment combinations

The two control treatments had not significantly increased the vine length at any of the stages However soil application increased the vine length compared to foliar application at all stages

Among the different treatment combinations including control, integrated application of water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas + Mg + B through drip irrigation registered significant improvement in vine length at all stage of growth and at 15 MAP there was 199 80 per cent increase over control mean

4 2 LEAF NUMBER

The effect of different methods of irrigation, levels of fertigation and their interactions on leaf number observed at 7, 9, 11, 13 and 15 MAP are furnished in Table 7

Methods of irrigation significantly influenced leaf number at all stages of growth Spectacular improvement in leaf number was observed with drip irrigation At 15 MAP, there was 11 76 per cent increase in leaf number with drip irrigation compared to sprinkler irrigation

Table 7 Leaf number as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	98 66	145 91	154 83	165 33	177 08
M_2	132 20	175 75	184 75	191 91	197 91
Fertigation					
F_1	110 25	174 25	182 00	191 00	196 75
F_2	114 50	133 25	140 75	153 25	168 75
F_3	113 75	184 00	192 50	195 75	200 25
F_4	129 50	150 75	162 50	171 75	181 50
F_5	107 75	165 00	174 25	183 25	190 50
F_6	117 00	157 75	166 75	176 75	187 25
Interaction effects					
M_1F_1	117 00	156 00	163 50	173 50	180 00
M_1F_2	92 50	118 00	125 50	139 00	161 50
M_1F_3	95 00	178 00	190 50	194 00	199 50
M_1F_4	105 00	127 00	140 00	151 50	163 00
M_1F_5	98 50	153 00	160 50	172 00	183 00
M_1F_6	84 00	143 50	149 00	162 00	175 50
M_2F_1	103 50	192 50	200 50	208 50	213 50
M_2F_2	136 50	148 50	156 00	167 50	176 00
M_2F_3	132 50	190 00	194 50	197 50	201 00
M_2F_4	154 00	174 50	185 00	192 00	200 00
M_2F_5	117 00	177 00	188 00	194 50	198 00
M_2F_6	150 00	172 00	184 50	191 50	199 00
Treatment mean	115 45	160 83	169 79	178 62	187 50
Controls					
CF	58 50	64 50	70 00	72 00	76 00
CS	72 00	55 50	62 00	64 50	66 50
Control mean	65 25	60 00	66 00	68 25	71 25
SE					
M	2 13	3 28	2 72	2 39	2 95
F	3 69	5 69	4 71	4 15	5 12
MF	5 22	8 05	6 66	5 87	7 24
CD (0 05)					
M	4 61	7 10	5 87	5 18	6 38
F	7 98	12 30	10 18	8 97	11 06
MF	11 29	NS	14 40	12 69	15 64
Treatment Vs Control	14 74	22 71	18 79	16 56	20 41
Between controls	11 29	NS	NS	NS	NS
Between treatments (including control)	11 29	17 40	14 40	12 69	15 64

MAP Months after planting

Similar to methods of irrigation, levels of fertigation also significantly influenced leaf production at all stages of growth In general fertigation with water soluble NPK + PGPR Mix– I + Fluorescent pseudomonas significantly and positively increased leaf number at all stages of growth except 7 MAP

Interaction effects also significantly contributed to increase in leaf number at all stages of growth except at 9 MAP The treatment combination M_2F_1 significantly increased the leaf number at 7, 11, 13 and 15 MAP

The two control treatments were insignificant in influencing leaf number at 9, 11, 13 and 15 MAP However positive and significant improvement in leaf number was observed at 7 MAP due to soil application and the per cent increase over foliar application was 23 07

Significant influence of different treatment combinations including control was observed on leaf number at all stages of growth and in general M_2F_1 recorded higher leaf number The highest leaf number of 213 50 was observed in M_2F_1 at 15 MAP which was 199 64 per cent higher compared to control mean

4 3 LEAF AREA INDEX

Leaf area index of long pepper as influenced by methods of irrigation and levels of fertigation and their interactions estimated at 7, 9, 11, 13 and 15 MAP are depicted in Table 8

Method of irrigation, levels of fertigation and their interactions significantly influenced leaf area index at all stages of growth Drip irrigation significantly improved leaf area index at 7, 9, and 13 MAP However significant influence of microsprinkler was observed at 11 and 15 MAP in improving leaf area index to the tune of 1 36 which was 3 81 per cent higher compared to drip irrigation

Table 8 Leaf area ındex as ınfluenced by methods of ırrıgatıon and levels of fertıgatıon

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of ırrıgatıon					
M_1	1 11	1 17	1 38	1 41	1 36
M_2	1 26	2 12	1 14	1 51	1 31
Fertıgatıon					
F_1	1 12	1 67	1 35	1 07	1 16
F_2	1 32	1 45	1 13	1 11	1 53
F_3	1 33	1 55	1 03	1 36	1 38
F_4	0 90	1 60	1 35	1 75	1 03
F_5	1 21	1 65	1 54	2 16	1 46
F_6	1 23	1 95	1 16	1 30	1 46
Interactıon effects					
M_1F_1	0 84	1 01	0 97	1 06	0 67
M_1F_2	1 23	0 96	1 55	1 33	2 14
M_1F_3	1 13	0 93	1 06	1 79	1 77
M_1F_4	0 88	0 98	1 97	1 58	0 96
M_1F_5	1 20	1 46	1 77	1 58	1 11
M_1F_6	1 37	1 67	0 95	1 11	1 52
M_2F_1	1 41	2 33	1 73	1 08	1 65
M_2F_2	1 42	1 94	0 70	0 89	0 91
M_2F_3	1 53	2 17	1 01	0 92	1 00
M_2F_4	0 91	2 23	0 74	1 92	1 11
M_2F_5	1 23	1 84	1 32	2 73	1 81
M_2F_6	1 10	2 24	1 36	1 49	1 40
Treatment mean	1 18	1 64	1 26	1 46	1 34
Controls					
CF	0 57	0 19	0 19	0 34	0 29
CS	0 50	0 50	0 24	0 22	0 38
Control mean	0 54	0 35	0 22	0 28	0 33
SE					
M	0 01	0 01	0 01	0 04	0 01
F	0 03	0 03	0 03	0 08	0 03
MF	0 04	0 04	0 04	0 12	0 04
CD (0 05)					
M	0 04	0 03	0 04	0 10	0 04
F	0 07	0 06	0 07	0 18	0 07
MF	0 10	0 09	0 10	0 25	0 10
Treatment Vs Control	0 13	0 12	0 13	0 33	0 13
Between controls	NS	0 09	NS	NS	NS
Between treatments (ıncludıng control)	0 10	0 09	0 10	0 25	0 10

MAP Months after plantıng

The effect of levels of fertigation on leaf area index was significant and F_3 on par with F_2, F_6, F_5, F_5 and F_2 registered higher LAI at 7, 9, 11, 13 and 15 MAP respectively At 15 MAP, F_2 recorded the highest LAI of 1 53 which was significantly different from all other levels of fertigation

Significance of interaction effects was evident at all stages of growth and M_2F_3 on par with M_2F_2 at 7 MAP, M_2F_1 on par with M_2F_6 and M_2F_4 at 9 MAP, M_1F_4 at 11 MAP, M_2F_5 at 13 MAP and M_1F_2 at 15 MAP registered higher values At 15 MAP the treatment combination M_1F_2 recorded highest leaf area index of 2 14 In the control treatments, foliar and soil application of nutrient sources influenced leaf area index only at 9 MAP Soil application of nutrients recorded a leaf area index of 0 38 compared to 0 29 in foliar application at 15 MAP

Positive and significant effect of methods of irrigation, levels of fertigation and their interactions were observed between treatments including control At 15 MAP the treatment combination M_1F_2 recorded the higher LAI of 2 14 which was 548 48 per cent higher compared to control mean

4 4 NUMBER OF BRANCHES

The effect of methods of irrigation, levels of fertigation and their interaction on number of branches recorded at 7, 9, 11, 13 and 15 MAP are presented in Table 9

Methods of irrigation significantly influenced the number of branches at all growth stages except at 7 MAP Drip irrigation was found effective in improving the number of branches at all stages At 15 MAP, drip irrigation recorded the highest number of branches of 33 41 which was 10 15 per cent higher compared to microsprinkler The effect of levels of fertigation on number of branches was appreciable at all growth stages except 7 MAP Fertigation with water soluble NPK fertilizer gave higher number of branches throughout the period of experimentation and the highest number of 35 25 was recorded at 15 MAP

Table 9 Number of branches as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	20 91	27 75	29 16	30 00	30 33
M_2	24 91	31 33	32 75	33 25	33 41
Fertigation					
F_1	25 50	33 75	34 75	35 25	35 25
F_2	22 50	27 25	29 25	30 50	30 75
F_3	23 25	33 50	33 75	34 25	34 25
F_4	24 00	27 75	30 00	30 50	31 00
F_5	21 75	29 50	30 00	30 75	31 25
F_6	20 50	25 50	28 00	28 50	28 75
Interaction effects					
M_1F_1	22 00	34 50	35 00	35 50	35 50
M_1F_2	21 00	24 50	26 00	28 00	28 50
M_1F_3	22 00	31 00	31 50	32 00	32 00
M_1F_4	23 00	27 00	29 00	29 50	30 00
M_1F_5	21 00	29 00	29 50	30 50	31 00
M_1F_6	16 50	20 50	24 00	24 50	25 00
M_2F_1	29 00	33 00	34 50	35 00	35 00
M_2F_2	24 00	30 00	32 50	33 00	33 00
M_2F_3	24 50	36 00	36 00	36 50	36 50
M_2F_4	25 00	28 50	31 00	31 50	32 00
M_2F_5	22 50	30 00	30 50	31 00	31 50
M_2F_6	24 50	30 50	32 00	32 50	32 50
Treatment mean	22 91	29 54	30 95	31 62	31 87
Controls					
CF	14 50	17 50	18 00	18 50	19 00
CS	20 00	23 50	24 00	24 50	25 00
Control mean	17 25	20 50	21 00	21 50	22 00
SE					
M	1 92	1 39	1 24	1 18	1 03
F	3 34	2 41	2 16	2 04	1 79
MF	4 72	3 41	3 05	2 89	2 54
CD (0 05)					
M	NS	3 01	2 69	2 55	2 24
F	NS	5 21	4 67	4 41	3 88
MF	NS	NS	NS	NS	NS
Treatment Vs Control	13 32	9 62	8 62	8 15	7 17
Between controls	NS	NS	NS	NS	5 49
Between treatments (including control)	4 72	7 37	6 60	6 24	5 49

MAP Months after planting

Interaction effects didn't significantly influence the number of branches at any of the growth stages of long pepper In general the performance of the treatment combination M_2F_3 was superior, though not significant

The two control treatments didn't differ significantly at 7, 9, 11, and 13 MAP However positive and significant influence of soil application (CS) was observed at 15 MAP which was resulted in higher branch number 25, which was 31 57 per cent higher compared to foliar application

Positive and significant influence of methods of irrigation, levels of fertigation and their interaction was observed between treatments including control at all growth stages At 15 MAP the treatment combination M_2F_3 resulted in the greatest number of branches of 36 50 which was 65 90 per cent higher compared to control mean

4 5 ROOT PARAMETERS

The influence of methods of irrigation, levels of fertigation and their interaction effects on root number, root length, root weight and root spread recorded at 7, 9, 11, 13 and 15 MAP are furnished in Tables 10, 11, 12 and 13 respectively

Methods of irrigation significantly influenced root number only at 11 and 13 MAP Microsprinkler was found to be beneficial in significantly improving root number At 15 MAP, microsprinkler recorded the highest root number of 36 91 The effect of levels of fertigation on root number was significant at all growth stages F_6 on par with F_3 at 7 MAP, F_3 on par with F_6, F_5, and F_4 at 9 MAP, F_6 on par with F_5, F_3 and F_4 at 11 MAP, F_5 on par with F_6 and F_3 at 13 MAP and F_5 at 15 MAP showed significantly superior values F_5 recorded highest root number of 47 50 at 15 MAP Interaction effects also recorded the significance of treatment combinations in increasing root number throughout the period of experimentation M_2F_3 on par with M_2F_6 at 7 MAP,

Table 10. Root number as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	14.25	22.41	28.66	33.08	36.91
M_2	15.66	22.00	25.16	28.75	33.50
Fertigation					
F_1	11.75	17.75	21.75	25.25	28.75
F_2	11.75	18.00	23.00	25.00	28.00
F_3	20.50	26.00	28.75	32.50	34.75
F_4	11.00	22.50	27.00	31.25	34.75
F_5	13.00	24.00	30.00	36.25	47.50
F_6	21.75	25.00	31.00	35.25	37.50
Interaction effects					
M_1F_1	17.00	24.00	28.00	31.50	33.50
M_1F_2	14.50	20.00	27.00	30.00	33.50
M_1F_3	14.00	19.00	23.00	29.00	31.00
M_1F_4	8.00	25.00	31.50	36.50	38.50
M_1F_5	11.50	24.00	32.00	38.00	51.00
M_1F_6	20.50	22.50	30.50	33.50	34.00
M_2F_1	6.50	11.50	15.50	19.00	24.00
M_2F_2	9.00	16.00	19.00	20.00	22.50
M_2F_3	27.00	33.00	34.50	36.00	38.50
M_2F_4	14.00	20.00	22.50	26.00	31.00
M_2F_5	14.50	24.00	28.00	34.50	44.00
M_2F_6	23.00	27.50	31.50	37.00	41.00
Treatment mean	14.95	22.20	26.91	30.91	35.20
Controls					
CF	12.50	16.50	16.50	18.50	20.00
CS	12.50	17.00	18.00	21.50	22.50
Control mean	12.50	16.75	17.25	20.00	21.25
SE					
M	1.02	1.43	1.06	1.10	1.70
F	1.76	2.48	1.84	1.92	2.96
MF	2.49	3.51	2.61	2.71	4.18
CD (0.05)					
M	NS	NS	2.30	2.39	NS
F	3.81	5.37	3.98	4.14	6.39
MF	5.39	7.59	5.64	5.86	9.04
Treatment Vs Control	7.04	9.91	7.36	7.65	11.80
Between controls	NS	NS	NS	NS	NS
Between treatments (including control)	5.39	7.59	5.64	5.86	9.04

MAP: Months after planting

Table 11. Root length (cm) as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	17.23	25.38	31.00	33.85	36.72
M_2	20.47	25.57	29.54	33.30	36.45
Fertigation					
F_1	16.47	27.12	30.30	31.92	36.27
F_2	16.37	24.35	27.42	32.97	35.72
F_3	20.00	24.45	32.37	34.32	36.12
F_4	20.52	26.77	31.97	34.40	37.02
F_5	21.15	27.15	28.12	31.80	34.22
F_6	18.60	23.02	31.42	36.05	40.17
Interaction effects					
M_1F_1	17.45	31:25	33.25	35.00	37.55
M_1F_2	18.30	22.75	28.20	35.50	39.25
M_1F_3	14.65	21.50	34.75	36.60	38.65
M_1F_4	15.75	24.90	29.30	30.25	32.10
M_1F_5	18.65	28.80	29.10	30.40	33.20
M_1F_6	18.60	23.10	31.40	35.40	39.60
M_2F_1	15.50	23.00	27.35	28.85	35.00
M_2F_2	14.45	25.95	26.65	30.45	32.20
M_2F_3	25.35	27.40	30.00	32.05	33.60
M_2F_4	25.30	28.65	34.65	38.55	41.95
M_2F_5	23.65	25.50	27.15	33.20	35.25
M_2F_6	18.60	22.95	31.45	36.70	40.75
Treatment mean	18.85	25.47	30.27	33.57	36.59
Controls					
CF	18.25	19.60	22.80	24.75	27.25
CS	17.95	21.10	25.70	27.00	28.55
Control mean	18.10	20.35	24.25	25.87	27.90
SE					
M	1.44	1.52	1.24	1.52	1.73
F	2.50	2.63	2.14	2.63	3.01
MF	3.53	3.73	3.03	3.73	4.25
CD (0.05)					
M	3.11	NS	NS	NS	NS
F	NS	NS	NS	NS	NS
MF	NS	NS	NS	NS	NS
Treatment Vs Control	NS	10.52	8.56	NS	NS
Between controls	NS	NS	NS	8.06	9.19
Between treatments (including control)	NS	NS	6.56	NS	NS

MAP: Months after planting

M_2F_3 on par with M_2F_6 and M_1F_4 at 9 MAP, M_2F_3 on par with M_1F_5, M_1F_4, M_2F_6 and M_1F_6 at 11 MAP, M_1F_5 on par with M_2F_6, M_1F_4, M_2F_3, M_2F_5, M_1F_6 at 13 MAP, and M_1F_5 on par with M_2F_5 at 15 MAP registered significantly higher root number compared to all other treatment combinations. No significant difference was observed between controls in influencing root number. Between treatments including controls were found to be positively and significantly influenced by methods of irrigation, levels of fertigation and their interactions at all stages of crop growth. The highest root number of 51.00 was recorded by the treatment combination M_1F_5 at 15 MAP which was 140 per cent higher over control mean.

Methods of irrigation influenced root length only at 7 MAP and drip irrigation was found beneficial. Though not significant, at 15 MAP microsprinkler registered higher root length of 36.72 cm. Levels of fertigation had no significant influence on root length at any stages of growth. Among the different levels of fertigation, F_6 recorded the highest root length of 40.17 cm at 15 MAP. Similar to the levels of fertigation interaction effects also didn't significantly influence root length at any stages of growth. The treatment combination M_2F_4 registered the greatest root length of 41.95 cm at 15 MAP. Significantly different effects of two control treatments was observed at 13 and 15 MAP and at both stages soil application registered higher values compared to foliar application. The significant effect between treatments including control on root length was observed only at 11 MAP and the highest number was recorded by the treatment combination M_1F_3 which was on par with M_2F_4, M_1F_1, M_2F_6, M_1F_6, M_2F_3, M_1F_4, M_1F_5, and M_1F_2. The greatest root length of 41.95 cm which was 50.35 per cent higher compared to control mean was recorded by the treatment combination M_2F_4 at 15 MAP.

Methods of irrigation significantly influenced root weight only at two stages of growth i.e., at 9 and 11 MAP and at both stages drip irrigation was found advantageous. Between the two methods of irrigation, drip irrigation recorded the highest root weight of 21.02 g at 15 MAP. Levels of fertigation significantly

Table 12. Root weight (g) as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	4.09	5.40	11.45	15.65	18.03
M_2	5.13	12.60	16.39	17.97	21.02
Fertigation					
F_1	5.67	8.91	11.59	15.15	17.75
F_2	4.39	6.13	12.32	14.89	18.65
F_3	4.08	9.65	13.44	17.35	19.12
F_4	4.90	11.30	16.84	19.10	22.02
$_5$	4.74	10.29	15.44	18.27	19.35
F_6	3.89	7.95	13.91	16.12	20.28
Interaction effects					
M_1F_1	4.92	6.22	7.01	12.90	14.99
M_1F_2	3.75	4.32	10.11	12.26	17.83
M_1F_3	3.70	4.29	8.60	15.12	15.92
M_1F_4	3.70	5.11	15.53	19.77	21.10
M_1F_5	4.88	7.42	15.23	18.09	19.16
M_1F_6	3.58	5.05	12.26	15.78	19.19
M_2F_1	6.43	11.61	16.18	17.40	20.51
M_2F_2	5.03	7.95	14.53	17.51	19.47
M_2F_3	4.46	15.00	18.29	19.57	22.32
M_2F_4	6.09	17.40	18.16	18.43	22.94
M_2F_5	4.60	13.17	15.66	18.46	19.54
M_2F_6	4.19	10.85	15.56	16.46	21.37
Treatment mean	4.61	9.04	13.92	16.81	19.53
Controls					
CF	4.13	10.95	12.49	15.50	16.39
CS	3.31	5.89	7.13	8.05	10.99
Control mean	3.72	8.42	9.81	11.78	13.69
SE					
M	0.49	0.55	0.91	1.22	1.67
F	0.86	0.96	1.58	2.11	2.89
MF	1.21	1.36	2.24	2.99	4.09
CD (0.05)					
M	NS	1.20	1.98	NS	NS
F	NS	2.09	NS	NS	NS
MF	NS	2.95	NS	NS	NS
Treatment Vs Control	NS	NS	6.33	8.44	11.54
Between controls	NS	2.95	4.85	6.46	NS
Between treatments (including control)	NS	NS	4.85	6.46	8.84

MAP: Months after planting

Table 13. Root spread (cm) as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	28.66	35.13	42.00	45.93	48.55
M_2	35.80	40.26	42.89	46.41	49.17
Fertigation					
F_1	24.42	33.17	40.60	44.37	46.05
F_2	36.85	41.17	42.02	46.87	51.52
F_3	30.35	37.00	44.62	47.25	49.45
F_4	31.52	34.95	39.75	43.10	46.60
F_5	36.77	39.40	44.17	48.97	50.45
F_6	33.47	40.50	43.52	46.47	49.10
Interaction effects					
M_1F_1	24.65	29.90	41.25	45.20	46.10
M_1F_2	35.05	41.00	41.75	46.95	52.90
M_1F_3	21.15	32.55	44.65	48.10	48.90
M_1F_4	27.45	31.90	37.30	39.85	45.65
M_1F_5	32.15	35.20	42.35	47.35	49.05
M_1F_6	31.55	40.25	44.75	48.15	48.70
M_2F_1	24.20	36.45	39.95	43.55	46.00
M_2F_2	38.65	41.35	42.30	46.80	50.15
M_2F_3	39.55	41.45	44.60	46.40	50.00
M_2F_4	35.60	38.00	42.20	46.35	47.55
M_2F_5	41.40	43.60	46.00	50.60	51.85
M_2F_6	35.40	40.75	42.30	44.80	49.50
Treatment mean	32.23	37.70	42.45	46.17	48.86
Controls					
CF	26.90	31.25	36.70	38.75	40.90
CS	31.65	34.25	34.95	36.20	41.25
Control mean	29.27	32.75	35.82	37.47	41.07
SE					
M	1.42	1.51	1.23	0.95	1.22
F	2.46	2.62	2.13	1.65	2.12
MF	3.48	3.71	3.01	2.33	3.00
CD (0.05)					
M	3.07	3.27	NS	NS	NS
F	5.32	NS	NS	3.57	NS
MF	7.53	NS	NS	NS	NS
Treatment Vs Control	NS	10.48	8.51	6.59	8.48
Between controls	NS	NS	NS	NS	NS
Between treatments (including control)	NS	8.03	6.52	5.04	6.50

MAP: Months after planting

influenced root weight only at 9 MAP and F_4 on par with F_5 and F_3 was found to be significantly different from other treatments. Though not significant the trend was similar at 11, 13 and 15 MAP. Interaction effects didn't significantly influence root growth at any stages of growth except 9 MAP. The treatment combination M_2F_4 which was on par with M_2F_3 registered the highest root weight of 17.40 g. Though not significant a similar trend was observed at 15 MAP as well. The significant effect of two control treatments in influencing root weight was observed at 9, 11 and 13 MAP and at all the three stages, foliar application recorded significantly higher values. A similar trend was observed at 7 and 15 MAP as well. The significant effect of treatment combinations including control was observed at 11, 13 and 15 MAP. At 11 MAP, M_2F_3 on par with M_2F_4, M_2F_1, M_2F_5, M_2F_6, M_1F_4, M_1F_5, and M_2F_2; At 13 MAP, M_1F_4 on par with M_2F_3, M_2F_5, M_2F_4, M_1F_5, M_2F_2, M_2F_1, M_2F_6, CF and M_1F_3; and at 15 MAP, M_2F_4 on par with M_2F_3, M_2F_6, M_1F_4, M_2F_1, M_2F_5, M_2F_2, M_1F_6, M_1F_5, M_1F_2, CF, M_1F_3 and M_1F_1 recorded higher root weight. The highest root weight of 22.94 g was recorded by the treatment combination M_2F_4 at 15 MAP which was 67.56 per cent higher compared to control mean.

At 7 and 9 MAP root spread was found to be significantly influenced by the methods of irrigation and at both stages drip irrigation enhanced the root spread. Levels of fertigation were found to significantly influence root spread only at 7 and 13 MAP. At 7 MAP F_2 on par with F_5 and F_6 and at 13 MAP F_5 on par with F_3, F_2 and F_6 registered higher root spread. The significant effect of interactions between methods of irrigation and levels of fertigation was observed only at 7 MAP and the treatment combination M_2F_5 registered highest value which was on par with M_2F_3, M_2F_2, M_2F_4, M_2F_6, and M_1F_2. The effect of two control treatments was insignificant in influencing root spread at any stage of plant growth. The significant influence of treatment combinations including control was evident on root spread at 9, 11, 13 and 15 MAP. At 9 MAP, M_2F_5 on par with M_2F_3, M_2F_2, M_1F_2, M_2F_6, M_1F_6, M_2F_4 and M_2F_1; at 11 MAP, M_2F_5 on par with M_1F_6, M_1F_3, M_2F_3, M_1F_5, M_2F_2, M_2F_6, M_2F_4, M_1F_2, M_1F_1, and M_2F_1; at

13 MAP, M_2F_5 on par with M_1F_6, M_1F_3, M_1F_5, M_1F_2, M_2F_2, M_2F_3 and M_2F_4; and at 15 MAP, M_1F_2 on par with M_2F_5, M_2F_2, M_2F_3, M_2F_6, M_1F_5, M_1F_3, M_1F_6 and M_2F_4 recorded significantly higher root spread. The greatest root spread of 52.90 cm was recorded by the treatment combination M_1F_2 at 15 MAP which was 28.80 per cent higher compared to control mean.

4.6. PHYSIOLOGICAL PARAMETERS

Mean data on relative leaf water content, stomatal conductance and SPAD meter reading recorded at 7, 9, 11, 13 and 15 MAP are given in Tables 14, 15 and 16 respectively.

Methods of irrigation, levels of fertigation and their interaction effect had no significant influence on relative leaf water content recorded at any stage of growth of long pepper. Between two controls significant difference with respect to RLWC was observed only at 13 MAP. Between treatments including control, the effect was significant only at 13 MAP and the treatment combination M_1F_4 on par with M_2F_3, M_2F_4, M_1F_5, M_1F_1, M_2F_5, M_1F_2, M_2F_6, M_1F_3, M_1F_6, M_2F_1 and CF recorded significantly higher RLWC. At 15 MAP, the treatment combination M_2F_2 recorded the highest RLWC of 90 per cent which was 7.59 per cent higher compared to control mean.

Methods of irrigation didn't significantly influence the stomatal conductance at any of the growth stages except at 9 MAP. Microsprinkler registered a positive and remarkable increase in stomatal conductance over drip irrigation. Though not significant the same trend prevailed throughout the period of experimentation. Levels of fertigation and interaction effects didn't significantly influence stomatal conductance at any of the growth stages. However, F_4, F_1, F_2, F_4 and F_5 registered greater values at 7, 9, 11, 13 and 15 MAP respectively. With respect to the interaction effects M_1F_4, M_1F_1, M_2F_2, M_1F_5 and M_1F_1 resulted in greater stomatal conductance. The two control treatments were on par in influencing stomatal conductance throughout the period

Table 14. Relative leaf water content as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	87.18	86.25	86.25	85.99	84.03
M_2	87.65	87.22	87.22	85.06	86.19
Fertigation					
F_1	87.05	87.38	84.35	84.64	85.47
F_2	86.38	86.40	75.22	83.35	84.61
F_3	89.14	88.75	83.84	86.29	85.22
F_4	86.72	83.76	82.49	87.92	86.47
F_5	88.27	87.48	79.31	86.16	85.15
F_6	86.94	86.61	84.43	84.78	83.75
Interaction effects					
M_1F_1	87.86	88.48	86.30	85.75	83.28
M_1F_2	86.74	88.68	81.61	85.61	79.22
M_1F_3	89.58	88.41	83.12	85.11	81.55
M_1F_4	85.72	78.58	81.75	88.69	86.53
M_1F_5	88.29	88.24	84.12	86.67	87.82
M_1F_6	84.92	85.11	84.46	84.12	85.80
M_2F_1	86.25	86.28	82.41	83.53	87.66
M_2F_2	86.03	84.13	68.83	81.09	90.00
M_2F_3	88.71	89.10	84.55	87.47	88.89
M_2F_4	87.72	88.94	83.23	87.14	86.40
M_2F_5	88.25	86.72	74.49	85.65	82.46
M_2F_6	88.98	88.10	84.40	85.46	81.71
Treatment mean	87.41	86.73	81.60	85.53	85.11
Controls					
CF	87.49	87.15	84.62	82.72	86.62
CS	85.35	85.66	78.22	75.01	80.67
Control mean	86.41	86.41	81.42	78.86	83.65
SE					
M	0.69	1.87	3.85	1.37	1.78
F	1.19	3.25	6.68	2.39	3.01
MF	1.69	4.60	9.45	3.38	4.26
CD (0.05)					
M	NS	NS	NS	NS	NS
F	NS	NS	NS	NS	NS
MF	NS	NS	NS	NS	NS
Treatment Vs Control	NS	NS	NS	9.54	NS
Between controls	NS	NS	NS	7.30	NS
Between treatments (including control)	NS	NS	NS	7.30	NS

MAP: Months after planting

Table 15. Stomatal conductance (CO_2 mmol/m^{2}s) as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	112.01	82.59	67.95	48.94	156.78
M_2	73.89	48.93	70.90	41.19	110.40
Fertigation					
F_1	54.17	103.52	40.90	54.67	138.67
F_2	104.02	55.60	110.95	23.37	146.72
F_3	78.80	48.95	36.60	19.00	128.40
F_4	127.50	70.25	45.97	60.15	137.72
F_5	106.27	64.67	91.00	56.70	151.07
F_6	86.95	51.57	91.15	56.50	98.97
Interaction effects					
M_1F_1	44.65	117.30	46.05	61.80	189.60
M_1F_2	108.60	70.10	47.75	24.95	158.30
M_1F_3	101.70	69.60	39.10	16.70	172.55
M_1F_4	174.75	86.75	41.75	67.85	137.30
M_1F_5	156.20	67.60	107.00	87.70	177.55
M_1F_6	86.20	84.20	126.05	34.65	105.40
M_2F_1	63.70	89.75	35.75	47.55	87.75
M_2F_2	99.45	41.10	174.15	21.80	135.15
M_2F_3	55.90	28.30	34.10	21.30	84.25
M_2F_4	80.25	53.75	50.20	52.45	138.15
M_2F_5	56.35	61.75	75.00	25.70	124.60
M_2F_6	87.70	18.95	56.25	78.35	92.55
Treatment mean	92.95	65.76	69.42	45.06	133.59
Controls					
CF	136.20	107.30	27.65	69.20	110.40
CS	156.90	49.20	81.85	95.25	128.15
Control mean	146.55	78.25	54.75	82.22	119.27
SE					
M	19.72	15.10	23.93	15.01	26.40
F	34.16	26.15	41.45	25.99	45.74
MF	48.31	36.99	58.62	36.76	64.69
CD (0.05)					
M	NS	32.62	NS	NS	NS
F	NS	NS	NS	NS	NS
MF	NS	NS	NS	NS	NS
Treatment Vs Control	NS	NS	NS	NS	NS
Between controls	NS	NS	NS	NS	NS
Between treatments (including controls)	NS	NS	NS	NS	NS

MAP: Months after planting

of experimentation. Between treatments including control also didn't significantly influence stomatal conductance at any stages of plant growth. The treatment combination M_1F_1 recorded the highest stomatal conductance of 189.60 at 15 MAP which was 58.96 per cent higher over control mean.

Methods of irrigation, levels of fertigation and their interaction effects had no significant influence on SPAD meter reading at any stages of crop growth. However between two methods of irrigation microsprinkler and among different levels of fertigation F_6 recorded higher SPAD meter reading at 15 MAP. The treatment combination M_1F_6 registered the highest SPAD meter reading of 57.20 among different treatment combinations. SPAD meter reading was not at all influenced by the effect of methods of nutrient application of the two control treatments. SPAD meter reading was considerably influenced by the effect of different treatment combination including two control treatments. At 7, 9, 11, 13 and 15 MAP all the twelve treatment combinations were on par and significantly different from the two control treatments with respect to the SPAD meter reading. M_2F_2, M_2F_6, M_2F_6, M_1F_1 and M_1F_6 showed higher SPAD meter reading at 7, 9, 11, 13 and 15 MAP respectively. At 15 MAP, M_1F_6 on par with M_2F_5, M_2F_3, M_1F_5, M_2F_6, M_1F_4, M_1F_2, M_2F_2, M_1F_1 and M_1F_3 registered the highest SPAD meter reading of 57.20 which was 54.17 per cent higher over control mean.

4.7. MICROMETEOROLOGICAL PARAMETERS

Mean data on leaf temperature, transpiration rate, total solar radiation and photosynthetically active radiation at 7, 9, 11, 13 and 15 MAP are enumerated in Tables 17, 18 and 19.

Methods of irrigation significantly influenced leaf temperature only at 13 MAP. In general leaf temperature was higher at all stages of growth except at 9 MAP when drip irrigation was practiced. Levels of fertigation had no significant effect on leaf temperature at any of the growth stages. However at 15 MAP F_3 recorded the highest leaf temperature of 35.25^0C. Interaction effects had also not

Table 16. SPAD meter reading as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	40.33	41.52	52.57	48.81	51.11
M_2	41.84	42.88	49.51	48.99	50.74
Fertigation					
F_1	39.85	40.10	49.55	51.55	47.90
F_2	41.82	44.02	49.60	52.02	49.40
F_3	39.65	39.02	48.65	50.30	51.30
F_4	40.85	43.95	47.37	45.35	48.42
F_5	42.35	42.45	53.87	49.42	54.05
F_6	42.00	43.67	57.22	44.77	54.50
Interaction effects					
M_1F_1	38.85	39.45	54.00	53.35	48.40
M_1F_2	37.50	42.60	53.20	51.10	49.50
M_1F_3	38.65	38.10	49.00	50.15	48.20
M_1F_4	42.05	44.05	47.10	44.20	50.60
M_1F_5	44.10	43.65	55.50	49.90	52.80
M_1F_6	40.85	41.30	56.65	44.20	57.20
M_2F_1	40.85	40.75	45.10	49.75	47.40
M_2F_2	46.15	45.45	46.00	52.95	49.30
M_2F_3	40.65	39.95	48.30	50.45	54.40
M_2F_4	39.65	43.85	47.65	46.50	46.25
M_2F_5	40.60	41.25	52.25	48.95	55.30
M_2F_6	43.15	46.05	57.80	45.35	51.80
Treatment mean	41.08	42.20	51.04	48.90	50.92
Controls					
CF	29.25	25.10	29.30	35.40	38.20
CS	28.25	32.55	34.65	34.15	36.00
Control mean	28.75	28.82	31.97	34.77	37.10
SE					
M	1.22	1.78	2.64	2.04	1.77
F	2.11	3.08	4.58	3.54	3.07
MF	2.99	4.36	6.47	5.01	4.34
CD (0.05)					
M	NS	NS	NS	NS	NS
F	NS	NS	NS	NS	NS
MF	NS	NS	NS	NS	NS
Treatment Vs Control	8.43	12.30	18.27	14.15	12.26
Between controls	NS	NS	NS	NS	NS
Between treatments (including control)	6.46	9.42	13.99	10.84	9.39

MAP: Months after planting

Table 17. Leaf temperature (^0C) as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	36.15	33.85	32.88	32.40	34.87
M_2	36.16	33.32	33.30	33.10	35.23
Fertigation					
F_1	36.32	33.70	33.07	32.75	34.90
F_2	35.65	33.37	32.52	32.60	34.82
F_3	35.10	34.22	33.27	32.42	35.25
F_4	36.82	33.15	33.57	32.92	35.17
F_5	36.07	33.75	33.22	32.55	35.00
F_6	36.97	33.35	32.90	33.25	35.17
Interaction effects					
M_1F_1	36.20	33.70	33.15	32.25	34.80
M_1F_2	34.95	34.30	32.50	32.05	34.50
M_1F_3	35.10	33.45	32.90	31.95	34.95
M_1F_4	37.35	34.00	33.15	33.10	35.00
M_1F_5	35.50	33.75	32.95	31.85	34.90
M_1F_6	37.80	33.95	32.65	33.20	35.10
M_2F_1	36.45	33.70	33.00	33.25	35.00
M_2F_2	36.35	32.45	32.55	33.15	35.15
M_2F_3	35.10	35.00	33.65	32.90	35.55
M_2F_4	36.30	32.30	34.00	32.75	35.35
M_2F_5	36.65	33.75	33.50	33.25	35.10
M_2F_6	36.15	32.75	33.15	33.30	35.25
Treatment mean	36.15	33.59	33.09	32.75	35.05
Controls					
CF	38.55	35.25	33.75	32.45	34.70
CS	39.05	34.45	33.40	32.95	34.95
Control mean	38.80	34.85	33.57	32.70	34.82
SE					
M	0.67	0.55	0.26	0.22	0.17
F	1.16	0.96	0.46	0.39	0.29
MF	1.65	1.36	0.65	0.55	0.41
CD (0.05)					
M	NS	NS	NS	0.49	NS
F	NS	NS	NS	NS	NS
MF	NS	NS	NS	NS	NS
Treatment Vs Control	4.66	NS	NS	NS	NS
Between controls	NS	NS	NS	NS	NS
Between treatments (including control)	3.57	NS	NS	NS	NS

MAP: Months after planting

Table 18. Transpiration rate (H_2O mmol/ m^2s) as influenced methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	2.31	1.33	1.01	0.90	2.08
M_2	1.83	0.84	1.13	0.91	1.48
Fertigation					
F_1	1.49	1.71	0.67	1.02	1.78
F_2	2.28	1.01	1.43	0.46	1.53
F_3	1.28	0.86	0.63	0.38	1.60
F_4	2.99	1.20	0.86	1.26	2.01
F_5	2.17	1.15	1.45	1.03	2.23
F_6	2.22	0.58	1.40	1.27	1.54
Interaction effects					
M_1F_1	1.01	2.01	0.65	1.03	2.40
M_1F_2	2.36	1.38	0.88	0.44	1.54
M_1F_3	1.26	1.10	0.57	0.31	2.41
M_1F_4	3.93	1.50	0.67	1.39	2.00
M_1F_5	3.00	1.15	1.58	1.51	2.52
M_1F_6	2.29	0.86	1.74	0.71	1.62
M_2F_1	1.97	1.41	0.69	1.01	1.17
M_2F_2	2.21	0.65	1.98	0.49	1.53
M_2F_3	1.30	0.63	0.70	0.46	0.80
M_2F_4	2.05	0.91	1.06	1.13	2.03
M_2F_5	1.34	1.16	1.31	0.55	1.95
M_2F_6	2.15	0.31	1.06	1.83	1.45
Treatment mean	2.07	1.09	1.07	0.90	1.78
Controls					
CF	4.02	2.01	0.36	1.35	1.58
CS	4.43	1.08	3.32	1.78	2.29
Control mean	4.22	1.55	1.84	1.56	1.93
SE					
M	0.45	0.25	0.33	0.22	0.29
F	0.78	0.44	0.58	0.39	0.51
MF	1.11	0.63	0.83	0.56	0.72
CD (0.05)					
M	NS	NS	NS	NS	NS
F	NS	NS	NS	NS	NS
MF	NS	NS	NS	NS	NS
Treatment Vs Control	3.14	NS	NS	1.58	NS
Between controls	NS	NS	1.79	NS	NS
Between treatments (including control)	2.40	NS	NS	1.21	NS

MAP: Months after planting

significantly influenced leaf temperature and highest leaf temperature of 35.55^{0}C was recorded by the treatment combination M_2F_3 at 15 MAP. Leaf temperature was not at all influenced by method of nutrient application in the control treatments. Compared to treatment and control means, control mean registered higher leaf temperature at all stages of growth except at 13 MAP. The effect of treatment combinations including control was significant only at 7 MAP and the highest leaf temperature of 39.05^{0}C was recorded in the control treatment CS. However at 15 MAP the treatment combination M_2F_3 and M_1F_2 recorded the highest and lowest leaf temperatures of 35.55^{0}C and 34.50^{0}C respectively.

Methods of irrigation, levels of fertigation and their interaction effects had no significant influence on transpiration rate at any of the crop growth stages. Effect of control treatments on transpiration rate was also found to non significant. The effect of treatment combinations including controls was found to be remarkably influence transpiration rate at 7 and 13 MAP. At 7 MAP M_1F_4 on par with M_1F5, M_2F_2, M_1F_6, M_2F_2, M_2F_6, M_2F_4 and M_2F_1 ; At 13 MAP M_2F_6 on par with M_1F_5, M_1F_4, M_2F_4, M_1F_1, M_2F_1 and M_1F6 registered significantly higher transpiration rates compared to all other treatment combinations and control treatment. The highest transpiration rate of 2.52 (H_2O mmol/ m^{2}s) was given by the treatment combination M_1F_5 at 15 MAP which was 30.56 per cent higher over control mean.

Table 19. Effect of poly cum shade house on the incidence of total solar radiation and PAR

MAP	Total Solar radiation (W m^{-2})		Photosynthetically active radiation (nm)	
	Control	Poly cum shade house	Control	Poly cum shade house
7 MAP	1060	337	552	133
9 MAP	1220	427	633	78
11 MAP	1282	484	608	172
13 MAP	1339	463	638	79
15 MAP	1493	483	654	92

Data on total solar radiation and PAR measured in the poly cum shade house erected in the interspaces of coconut garden and in the open interspaces indicate higher values of both the microclimate parameters in the open interspaces of coconut garden compared to poly cum shade house.

4.8. NUMBER OF SPIKES

Effect of methods of irrigation, levels of fertigation and interactions on mean data on number of spikes per plant recorded at 7, 9, 11, 13 and 15 MAP are depicted in Table 20. Except at 7 MAP methods of irrigation significantly increased the spike number per plant and microsprinkler irrigation showed superiority over drip method. Microsprinkler irrigation recorded the highest total number of spikes of 43.41 which was 71.90 per cent higher compared to drip irrigation. At all stages of growth considerable improvement in spike number was evident due to the effect of levels of fertigation. F_2 on par with F_3 at 7 MAP, F_3 at 9 MAP, and F_3 on par with F_6 at 11 MAP, F_3 on par with F_6 at 13 MAP, and F_3 on par with F_6 at 15 MAP recorded appreciable increase in spike number. F_3 recorded the highest spike number of 47 per plant. Except at 7 MAP interaction effects significantly improved spike number and total number of spikes. At 9 MAP M_1F_3, at 11 MAP M_1F_3 on par with M_1F_6 and M_1F_5, at 13 MAP M_1F_3 on par with M_1F_6, at 15 MAP M_1F_3 on par with M_1F_6 registered significantly higher spike number. The treatment combination M_1F_3 recorded highest total number of spikes per plant which was significantly different from all other treatment combinations. No significant difference was observed between the two control treatments in influencing spike number at various stages and total spike number per plant. Remarkable improvement in spike number per harvest and total spike number was observed due to the effect of different treatment combinations including control. The highest total spike number of 62.50 was recorded by the treatment combination M_1F_3 which was 525 per cent higher compared to control mean.

Table 20. Number of spikes (per plant) as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP	Total
Methods of irrigation						
M_1	2.25	4.91	17.33	10.33	8.58	43.41
M_2	2.00	3.08	8.41	5.58	6.16	25.25
Fertigation						
F_1	1.25	2.00	11.00	6.00	5.25	25.50
F_2	2.75	4.75	11.50	7.50	7.00	33.50
F_3	2.75	6.25	17.75	10.75	9.50	47.00
F_4	2.00	3.25	10.00	5.50	6.75	27.50
F_5	2.00	4.00	12.75	7.75	6.25	32.75
F_6	2.00	3.75	14.25	10.25	9.50	39.75
Interaction effects						
M_1F_1	1.50	3.00	15.50	7.50	4.50	32.00
M_1F_2	3.00	5.00	16.50	10.00	7.50	42.00
M_1F_3	3.00	8.50	22.50	15.50	13.00	62.50
M_1F_4	2.00	3.50	10.50	5.50	6.00	27.50
M_1F_5	2.00	5.50	18.00	10.00	9.00	44.50
M_1F_6	2.00	4.00	21.00	13.50	11.50	52.00
M_2F_1	1.00	1.00	6.50	4.50	6.00	19.00
M_2F_2	2.50	4.50	6.50	5.00	6.50	25.00
M_2F_3	2.50	4.00	13.00	6.00	6.00	31.50
M_2F_4	2.00	3.00	9.50	5.50	7.50	27.50
M_2F_5	2.00	2.50	7.50	5.50	3.50	21.00
M_2F_6	2.00	3.50	7.50	7.00	7.50	27.50
Treatment mean	2.12	4.00	12.87	7.95	7.37	34.33
Controls						
CF	1.00	2.00	3.50	3.00	3.00	12.50
CS	1.00	1.00	2.50	1.50	1.50	7.50
Control mean	1.00	1.50	3.00	2.25	2.25	10.00
SE`						
M	0.20	0.25	0.97	0.44	0.65	1.78
F	0.34	0.43	1.68	0.77	1.14	3.09
MF	0.49	0.62	2.37	1.09	1.61	4.37
CD (0.05)						
M	NS	0.54	2.09	0.96	1.42	3.85
F	0.75	0.94	3.63	1.67	2.46	6.67
MF	NS	1.33	5.13	2.37	3.48	9.44
Treatment Vs Control	1.39	1.74	6.70	3.10	4.55	12.32
Between controls	NS	NS	NS	NS	NS	NS
Between treatments (including control)	1.06	1.33	5.13	2.37	3.48	9.44

MAP: Months after planting

4.9. SPIKE YIELD

Mean data on fresh spike yield per plant, dry spike yield per plant, fresh spike yield per hectare and dry spike yield per hectare are enumerated in Tables 21 to 24.

Spectacular improvement in fresh spike yield per plant at various growth stages and total spike yield per plant were evident with microsprinkler irrigation. Microsprinkler recorded 28.10 g total fresh spike yield per plant which was 76.84 per cent higher over drip irrigation. Levels of fertigation also significantly influenced both fresh spike yield per plant and total spike yield per plant. F_2 on par with F_3, F_3, F_3 on par with F_6, F_6 on par with F_3 and F_2, F_6 on par with F_3 and F_2, significantly recorded higher spike yield per plant at 7, 9, 11, 13 and 15 MAP respectively. F_3 on par with F_6 significantly contributed total spike yield per plant. Interaction effects also indicated its significance on fresh spike yield per plant at all stages of growth except at 7 MAP. The treatment combination M_1F_3 at 9 MAP, M_1F_3 on par with M_1F_6, M_1F_5 and M_1F_2 at 11 MAP, M_1F_3 on par with M_1F_6 and M_1F_2 at 13 MAP; and M_1F_3 on par with M_1F_6 at 15 MAP gave higher fresh spike yield per plant. Similar to the number of spikes per plant the two control treatments had no significant effect on fresh spike yield per plant and total spike yield per plant. The effect of treatment combinations including control on fresh spike yield per plant was evident at all stages of harvest including total fresh spike yield per plant. The treatment combination M_1F_3 on par with M_1F_6 registered the highest total fresh spike yield of 37.68 g per plant which was 858.77 per cent higher compared to control mean.

Methods of irrigation significantly influenced total dry spike yield and dry spike yield per plant at all stages of growth except at 7 MAP. Similar to the fresh spike yield per plant microsprinkler irrigation significantly contributed to dry spike production per plant. Similarly total dry spike yield per plant and dry spike yield per plant at various harvests were found to be significantly influenced by levels of fertigation.

Table 21. Fresh spike yield per plant (g) as influenced methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP	Total
Methods of irrigation						
M_1	1.46	2.98	11.68	6.90	5.07	28.10
M_2	1.27	1.97	5.48	3.49	3.66	15.89
Fertigation						
F_1	0.80	1.20	7.13	3.88	2.91	15.93
F_2	1.84	3.05	8.28	5.75	4.42	23.36
F_3	1.77	3.74	11.24	6.50	5.64	28.91
F_4	1.28	2.19	6.75	3.68	3.95	17.86
F_5	1.25	2.36	8.64	4.84	3.60	20.71
F_6	1.25	2.32	9.41	6.52	5.69	25.21
Interaction effects						
M_1F_1	0.84	1.55	9.88	4.72	2.17	19.18
M_1F_2	1.92	3.29	12.36	8.38	4.97	30.94
M_1F_3	1.69	4.85	14.30	9.24	7.58	37.68
M_1F_4	1.50	2.36	7.18	3.80	3.74	18.60
M_1F_5	1.45	3.15	12.46	6.43	4.92	28.43
M_1F_6	1.36	2.65	13.88	8.83	7.05	33.79
M_2F_1	0.76	0.84	4.38	3.04	3.64	12.68
M_2F_2	1.77	2.81	4.20	3.12	3.87	15.79
M_2F_3	1.84	2.62	8.19	3.76	3.71	20.13
M_2F_4	1.07	2.01	6.32	3.55	4.16	17.12
M_2F_5	1.05	1.58	4.83	3.24	2.27	12.99
M_2F_6	1.15	1.98	4.94	4.22	4.33	16.64
Treatment mean	1.37	2.47	8.58	5.19	4.37	22.00
Controls						
CF	0.46	0.80	1.02	0.75	1.61	4.65
CS	0.46	0.57	0.78	0.72	0.67	3.21
Control mean	0.46	0.68	0.90	0.73	1.14	3.93
SE						
M	0.08	0.09	0.64	0.28	0.43	1.13
F	0.14	0.17	1.11	0.49	0.75	1.96
MF	0.20	0.24	1.57	0.69	1.07	2.78
CD (0.05)						
M	0.17	0.214	1.38	0.61	0.94	2.45
F	0.30	0.371	2.40	1.06	1.64	4.25
MF	NS	0.525	3.40	1.50	2.31	6.01
Treatment Vs Control	0.57	0.685	4.43	1.96	3.02	7.85
Between controls	NS	NS	NS	NS	NS	NS
Between treatments (including control)	0.43	0.525	3.40	1.50	2.31	6.01

MAP: Months after planting

Table 22. Dry spike yield per plant (g) as influenced by methods of irrigation and levels of fertigation.

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP	Total
Methods of irrigation						
M_1	0.19	0.38	1.48	1.02	0.92	3.98
M_2	0.17	0.28	0.82	0.45	0.64	2.36
Fertigation						
F_1	0.11	0.17	0.86	0.51	0.51	2.15
F_2	0.24	0.43	1.19	0.77	0.77	3.40
F_3	0.23	0.49	1.55	0.96	1.02	4.25
F_4	0.17	0.29	1.21	0.50	0.71	2.87
F_5	0.16	0.32	0.68	0.71	0.64	2.50
F_6	0.16	0.31	1.40	0.97	1.02	3.85
Interaction effects						
M_1F_1	0.13	0.21	0.99	0.63	0.38	2.35
M_1F_2	0.25	0.44	1.76	1.12	0.88	4.45
M_1F_3	0.23	0.61	1.97	1.46	1.35	5.61
M_1F_4	0.18	0.31	1.47	0.57	0.67	3.21
M_1F_5	0.17	0.38	0.61	0.92	0.91	2.99
M_1F_6	0.17	0.35	2.05	1.42	1.30	5.29
M_2F_1	0.08	0.13	0.72	0.39	0.63	1.95
M_2F_2	0.24	0.41	0.62	0.42	0.66	2.35
M_2F_3	0.24	0.37	1.12	0.47	0.68	2.89
M_2F_4	0.15	0.26	0.95	0.42	0.75	2.54
M_2F_5	0.15	0.25	0.75	0.49	0.37	2.01
M_2F_6	0.14	0.27	0.75	0.52	0.74	2.42
Treatment mean	0.18	0.33	1.15	0.74	0.78	3.17
Controls						
CF	0.07	0.10	0.14	0.09	0.29	0.70
CS	0.08	0.08	0.13	0.10	0.10	0.47
Control mean	0.07	0.09	0.13	0.09	0.19	0.58
SE						
M	0.02	0.03	0.07	0.03	0.05	0.14
F	0.04	0.06	0.13	0.06	0.10	0.24
MF	0.05	0.09	0.19	0.09	0.14	0.35
CD (0.05)						
M	NS	0.08	0.16	0.08	0.12	0.31
F	0.08	0.14	0.29	0.14	0.22	0.53
MF	NS	NS	0.41	0.21	0.31	0.76
Treatment Vs Control	0.16	0.26	0.54	0.27	0.40	0.99
Between controls	NS	NS	NS	NS	NS	NS
Between treatments (including control)	0.12	0.20	0.41	0.21	0.31	0.76

MAP: Months after planting

F_3 on par with F_6 registered total dry spike yield of 4.25 g per plant. Interaction effects also significantly influenced total dry spike yield per plant at 11, 13 and 15 MAP. At 11 MAP, M_1F_6 on par with M_1F_3 and M_1F_2, at 13 MAP M_1F_3 on par with M_1F_6; and at 15 MAP M_1F_3 on par with M_1F_6 gave significantly higher spike yield per plant. The remarkable contribution of treatment combination M_1F_3 was evident on total dry spike yield per plant as well (5.61 g per plant). Similar to fresh spike yield per plant, dry spike yield per plant and total dry spike yield per plant were not at all found to be influenced by the method of nutrient application in the control plot. The effect of treatment combination including control on total dry spike yield per plant and dry spike yield per plant at various harvest was significant and similar to fresh spike yield per plant and total fresh spike yield per plant. Similar to total fresh spike yield per plant, the highest total dry spike yield per plant of 5.61g was recorded by the treatment combination M_1F_3 which was 867.24 per cent higher compared to control mean and was on par with M_1F_6.

Similar to total fresh spike yield per plant and fresh spike yield per plant at various harvest, total fresh spike yield per hectare and fresh spike yield per hectare at various harvests were found to be significantly influenced by the main and interaction effects of treatments including control. The trend was similar with respect to the fresh and dry spike yield per plant.

In general, similar to total dry spike yield per plant and dry spike yield per plant at various harvest; total dry spike yield per hectare and dry spike yield per hectare at various harvest were found to be significantly influenced by the main and interaction effects of treatments including control. Similar results were obtained with respect to both parameters.

4.10. DRY MATTER PRODUCTION

Mean data on dry matter production per plant recorded at 7, 9, 11, 13 and 15 MAP are furnished in Table 25. Methods of irrigation significantly

Table 23. Fresh spike yield (kg ha^{-1}) as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP	Total
Methods of irrigation						
M_1	91.50	186.27	730.12	431.50	317.33	1756.72
M_2	79.89	123.69	342.50	218.16	229.16	993.42
Fertigation						
F_1	50.50	75.00	446.00	242.50	182.00	996.00
F_2	115.50	191.00	518.00	359.50	276.50	1460.50
F_3	110.68	233.81	702.87	406.50	353.00	1806.87
F_4	80.50	137.07	422.00	230.00	247.00	1116.57
F_5	78.50	148.00	540.50	302.50	225.00	1294.50
F_6	78.50	145.00	588.50	408.00	356.00	1576.00
Interaction effects						
M_1F_1	53.00	97.00	618.00	295.00	136.00	1199.00
M_1F_2	120.00	206.00	773.00	524.00	311.00	1934.00
M_1F_3	106.00	303.62	893.75	578.00	474.00	2355.37
M_1F_4	94.00	148.00	449.00	238.00	234.00	1163.00
M_1F_5	91.00	197.00	779.00	402.00	308.00	1777.00
M_1F_6	85.00	166.00	868.00	552.00	441.00	2112.00
M_2F_1	48.00	53.00	274.00	190.00	228.00	793.00
M_2F_2	111.00	176.00	263.00	195.00	242.00	987.00
M_2F_3	115.37	164.00	512.00	235.00	232.00	1258.37
M_2F_4	67.00	126.15	395.00	222.00	260.00	1070.15
M_2F_5	66.00	99.00	302.00	203.00	142.00	812.00
M_2F_6	72.00	124.00	309.00	264.00	271.00	1040.00
Treatment mean	85.69	154.98	536.31	324.83	273.25	1375.07
Controls						
CF	29.00	50.00	64.00	47.00	101.00	291.00
CS	29.00	36.00	49.00	45.00	42.00	201.00
Control mean	29.00	43.00	56.50	46.00	71.50	246.00
SE						
M	5.17	6.20	40.16	17.77	27.40	71.03
F	8.95	10.74	69.56	30.79	47.45	123.03
MF	12.66	15.19	98.38	43.54	67.11	173.99
CD (0.05)						
M	11.17	13.40	86.77	38.40	59.19	153.45
F	19.34	23.21	150.29	66.51	102.52	265.79
MF	NS	32.83	212.54	94.07	144.99	375.89
Treatment Vs Control	35.71	42.86	277.44	122.79	189.27	490.66
Between controls	NS	NS	NS	NS	NS	NS
Between treatments (including control)	27.36	32.83	212.54	94.07	144.99	375.89

MAP: Months after planting

Table 24. Dry spike yield (kg ha^{-1}) as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP	Total
Methods of irrigation						
M_1	11.75	23.97	92.23	63.78	57.22	248.97
M_2	10.42	17.65	51.20	28.22	39.92	147.43
Fertigation						
F_1	6.73	10.50	53.49	31.95	31.83	134.50
F_2	15.14	26.67	74.54	47.99	48.10	212.45
F_3	14.47	30.72	96.69	60.28	63.48	265.65
F_4	10.41	18.02	75.70	31.00	44.50	179.65
F_5	9.91	19.70	42.34	44.09	40.03	156.09
F_6	9.86	19.26	87.53	60.68	63.51	240.86
Interaction effects						
M_1F_1	8.35	13.04	62.09	39.67	24.00	147.15
M_1F_2	15.40	27.44	110.15	70.05	54.98	278.11
M_1F_3	14.08	38.02	123.20	91.03	84.57	350.90
M_1F_4	11.20	19.60	91.86	35.76	42.07	200.49
M_1F_5	10.56	23.92	37.90	57.61	56.67	186.66
M_1F_6	10.86	21.84	128.19	88.57	81.07	330.53
M_2F_1	5.11	7.960	44.89	24.23	39.66	121.85
M_2F_2	14.79	25.91	38.93	25.94	41.23	146.80
M_2F_3	14.87	23.43	70.18	29.53	42.39	180.40
M_2F_4	9.63	16.44	59.55	26.25	46.94	158.81
M_2F_5	9.27	15.48	46.79	30.58	23.40	125.52
M_2F_6	8.86	16.69	46.88	32.80	45.95	151.18
Treatment mean	11.08	20.81	71.71	46.00	48.57	198.20
Controls						
CF	4.48	6.40	8.85	5.87	17.94	43.55
CS	4.72	4.70	7.98	6.00	6.17	29.57
Control mean	4.60	5.55	8.41	5.93	12.05	36.56
SE						
M	1.46	2.37	4.91	2.48	3.68	8.99
F	2.53	4.11	8.50	4.30	6.37	15.58
MF	3.58	5.82	12.02	6.08	9.01	22.04
CD (0.05)						
M	NS	5.13	10.60	5.36	7.95	19.44
F	5.48	8.89	18.37	9.29	13.77	33.67
MF	NS	NS	25.98	13.14	19.48	47.62
Treatment Vs Control	10.11	16.41	33.92	17.15	25.43	62.16
Between controls	NS	NS	NS	NS	NS	NS
Between treatments (including control)	5.48	12.57	25.98	13.14	19.48	47.62

MAP: Months after planting

Table 25. Dry matter production per plant (g) as influenced by methods of irrigation and levels of fertigation

Treatments	7 MAP	9 MAP	11 MAP	13 MAP	15 MAP
Methods of irrigation					
M_1	20.78	24.43	30.00	34.19	43.37
M_2	23.03	35.56	35.69	40.23	47.43
Fertigation					
F_1	20.06	24.36	26.73	33.50	38.95
F_2	19.23	25.11	34.76	38.92	51.81
F_3	22.74	33.55	24.84	27.35	38.38
F_4	24.98	32.85	39.79	45.78	51.60
F_5	21.78	33.08	36.13	39.36	45.58
F_6	22.65	31.04	34.83	38.38	46.06
Interaction effects					
M_1F_1	16.68	18.84	20.67	29.23	37.45
M_1F_2	16.71	18.72	32.57	36.80	57.91
M_1F_3	19.46	22.10	24.26	27.27	36.48
M_1F_4	23.29	29.67	37.87	45.24	50.25
M_1F_5	24.65	28.56	33.31	34.49	40.03
M_1F_6	23.89	28.73	31.34	32.13	38.07
M_2F_1	23.44	29.89	32.79	37.78	40.45
M_2F_2	21.75	31.50	36.96	41.04	45.70
M_2F_3	26.02	45.00	25.42	27.43	40.28
M_2F_4	26.67	36.03	41.70	46.31	52.95
M_2F_5	18.91	37.61	38.95	44.23	51.12
M_2F_6	21.42	33.35	38.32	44.62	54.05
Treatment mean	21.91	30.00	32.85	37.21	45.40
Controls					
CF	20.12	21.82	22.84	23.04	25.15
CS	23.10	23.54	24.40	25.12	26.48
Control mean	21.61	22.68	23.62	24.08	25.82
SE					
M	0.88	2.38	1.62	2.01	1.29
F	1.53	4.12	2.81	3.48	2.23
MF	2.17	5.83	3.98	4.93	3.16
CD (0.05)					
M	1.92	5.15	3.51	4.35	2.79
F	3.32	NS	6.08	7.53	4.83
MF	4.70	NS	NS	NS	6.84
Treatment Vs Control	NS	16.46	11.22	13.90	8.93
Between controls	NS	NS	NS	NS	NS
Between treatments (including control)	NS	12.61	8.59	10.65	6.84

MAP: Months after planting

increased dry matter production at all stages and remarkable effect of drip irrigation was evident throughout the stages of experimentation. Though levels of fertigation significantly influenced dry matter production at all harvest except at 9 MAP the trend was not uniform. F_4 at 7, 11 and 13 MAP and F_2 at 15 MAP recorded the highest dry matter production. Remarkable increase in dry matter production was observed due to the interaction effects only at 7 and 1 5MAP. At 7 MAP, M_2F_4 on par with M_2F_3, M_1F_5, M_1F_6, M_2F_1 and M_1F_4; and at 15 MAP, M_1F_2 on par with M_2F_6, M_2F_4 and M_2F_5 gave higher dry matter production per plant. The two control treatments had no significant effect on dry matter production per plant. Except at 7 MAP, the treatment combinations including control exerted significant influence on dry matter production at all other stages i.e., 9, 11, 13 and 15 MAP. The treatment combination M_1F_2 recorded the highest dry matter production of 57.91 g per plant at 15 MAP which was 124.28 per cent higher compared to control mean.

4.11. QUALITY ATTRIBUTES

Mean data on crude extract per cent and total crude extract production per hectare are presented in the Table 26. Methods of irrigation didn't significantly influence the crude extract content. However levels of fertigation remarkably influenced the crude extract per cent and F_3 on par with F_5, F_1 and F_6 recorded significantly higher values. Interaction effects also showed its effect in influencing crude extract per cent. M_2F_6 on par with M_1F_5, M_2F_3 and M_1F_1 registered significantly higher values compared to all other treatment combinations. The control treatments were insignificant in influencing crude extract per cent. The effect of treatment combinations including control indicated the significantly superior performance of the treatment combination M_2F_6 (5.97 per cent) which was 11.38 per cent higher compared to control mean.

Total crude extract production per unit area was also found to be remarkably influenced by the main and interaction effects of treatments including control. Similar to the total dry spike production per hectare, total crude extract

Table 26. Crude extract and total crude extract production as influenced by methods of irrigation and levels of fertigation

Treatments	Crude extract (%)	Dry spike yield (kg ha^{-1})	Total crude extract (kg ha^{-1})
Methods of irrigation			
M_1	5.54	248.97	13.70
M_2	5.55	147.43	8.19
Fertigation			
F_1	5.68	134.50	7.65
F_2	5.23	212.45	11.16
F_3	5.72	265.65	15.10
F_4	5.35	179.65	9.66
F_5	5.71	156.09	8.97
F_6	5.59	240.86	13.13
Interaction effects			
M_1F_1	5.79	147.15	8.53
M_1F_2	5.26	278.11	14.65
M_1F_3	5.59	350.90	19.65
M_1F_4	5.53	200.49	11.12
M_1F_5	5.89	186.66	11.00
M_1F_6	5.21	330.53	17.23
M_2F_1	5.56	121.85	6.77
M_2F_2	5.21	146.80	7.66
M_2F_3	5.85	180.40	10.55
M_2F_4	5.16	158.81	8.20
M_2F_5	5.53	125.52	6.94
M_2F_6	5.97	151.18	9.02
Treatment mean	5.55	198.20	10.94
Controls			
CF	5.35	43.55	2.33
CS	5.36	29.57	1.58
Control mean	5.36	36.56	1.96
SE			
M	0.046	8.99	0.55
F	0.080	15.58	0.95
MF	0.113	22.04	1.35
CD (0.05)			
M	NS	19.44	1.19
F	0.17	33.67	2.06
MF	0.24	47.62	2.92
Treatment Vs Control	0.31	62.16	3.82
Between controls	NS	NS	NS
Between treatments (including control)	0.24	47.62	2.92

Table 27. Plant nutrient status as influenced by methods of irrigation and levels of fertigation

Treatments	N (%)	P (%)	K (%)	Mg (%)	B (ppm)
Methods of irrigation					
M_1	2.14	0.072	2.95	0.174	22.49
M_2	2.14	0.088	2.92	0.177	27.99
Fertigation					
F_1	1.95	0.088	2.65	0.170	22.33
F_2	2.24	0.071	2.93	0.169	20.36
F_3	2.14	0.085	2.75	0.146	18.12
F_4	2.15	0.077	3.12	0.174	27.90
F_5	2.25	0.081	3.00	0.195	32.37
F_6	2.11	0.078	3.18	0.197	30.36
Interaction effects					
M_1F_1	1.92	0.099	2.52	0.172	17.52
M_1F_2	2.16	0.045	2.67	0.167	15.59
M_1F_3	2.20	0.070	2.77	0.128	11.09
M_1F_4	2.10	0.055	3.30	0.173	28.92
M_1F_5	2.36	0.078	2.92	0.195	31.40
M_1F_6	2.11	0.087	3.52	0.208	30.45
M_2F_1	1.98	0.077	2.77	0.170	27.15
M_2F_2	2.32	0.098	3.20	0.170	25.14
M_2F_3	2.08	0.100	2.72	0.164	25.16
M_2F_4	2.21	0.100	2.95	0.174	26.89
M_2F_5	2.14	0.084	3.07	0.196	33.34
M_2F_6	2.12	0.069	2.85	0.185	30.27
Treatment mean	2.14	0.074	2.94	0.175	25.24
Controls					
CF	1.06	0.078	1.82	0.062	15.81
CS	1.28	0.070	2.17	0.096	22.36
Control mean	1.17	0.080	2.00	0.079	19.09
SE					
M	0.02	0.005	0.17	0.007	1.96
F	0.04	0.010	0.29	0.012	3.40
MF	0.67	0.014	0.42	0.017	4.81
CD (0.05)					
M	NS	0.012	NS	NS	4.24
F	0.10	NS	NS	0.026	7.35
MF	0.14	0.030	NS	NS	NS
Treatment Vs Control	0.19	NS	1.18	0.048	13.57
Between controls	0.14	NS	NS	NS	NS
Between treatments (including control)	0.14	NS	0.90	0.037	10.40

production per hectare was also found to be significantly contributed by microsprinkler method of irrigation. Levels of fertigation enhanced total crude extract production per hectare and the highest value of 15.10 kg ha^{-1} was recorded by F_3 which was on par with F_6. Total crude extract production was also found to be significantly influenced by interaction effects and the treatment combination M_1F_3 (19.65 kg ha^{-1}) on par with M_1F_6 registered higher values. The two control treatments had no significant influence on total crude extract production. The treatment combinations including control appreciably influenced total crude extract production per hectare and the highest production of 19.65 kg ha^{-1} was recorded by the treatment combination M_1F_3 which was 902.55 per cent higher compared to control mean.

4.12. PLANT NUTRIENT STATUS

Total uptake of plant nutrients namely N, P, K, Mg and B estimated at 15 MAP are depicted in Table 27. Methods of irrigation significantly influenced phosphorous and boron contents only and in both cases drip irrigation was found to be beneficial. Levels of fertigation significantly influenced nitrogen, magnesium and boron concentrations. F_5 on par with F_2, F_4 and F_3, F_6 on par with F_5 and F_4, F_5 on par with F_6 and F_4 significantly increased N, Mg and B contents respectively. Nitrogen and phosphorous contents alone were significantly influenced by the interaction effects. M_1F_5 on par with M_2F_2 and M_2F_4; and M_2F_3 on par with M_2F_4, M_1F_1, M_2F_2, M_1F_6, M_2F_5, M_1F_5, M_2F_1, and M_1F_3 gave significantly higher values of N and P respectively. The two control treatments were insignificant in influencing P, K, Mg and B contents whereas the nitrogen concentration was found highest with CS and per cent increase over CF was 20.75. The effect of treatment combinations including control was appreciable in increasing N, K, Mg and B concentrations. M_1F_5 on par with M_2F_2 and M_2F_4; M_1F_6 on par with M_1F_4, M_2F_2, M_2F_5, M_2F_4, M_1F_5, M_2F_6, M_1F_3, M_2F_1, M_2F_3, and M_1F_2; M_1F_6 on par with M_2F_5, M_1F_5, M_2F_6, M_2F_4, M_1F_4, and M_1F_1; M_2F_5 on par with M_1F_5, M_1F_6, M_2F_6, M_1F_4, M_2F_1, M_2F_4, M_2F_3 and M_2F_2 recorded significantly higher content of N, K, Mg and B respectively.

Table 28. Total uptake of nutrients as influenced by methods of irrigation and levels of fertigation

Treatments	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Mg (kg ha^{-1})	B (g ha^{-1})
Methods of irrigation					
M_1	56.84	1.84	78.29	4.62	59.24
M_2	62.80	2.56	85.86	5.21	82.48
Fertigation					
F_1	46.81	2.12	63.70	4.11	53.93
F_2	71.15	2.18	92.72	5.38	63.17
F_3	49.92	2.00	64.17	3.44	43.31
F_4	68.62	2.48	99.55	5.54	88.37
F_5	62.79	2.28	84.75	5.49	90.86
F_6	59.64	2.14	87.59	5.50	85.54
Interaction effects					
M_1F_1	44.33	2.32	58.22	3.98	40.19
M_1F_2	76.98	1.60	95.38	5.96	55.60
M_1F_3	48.37	1.53	61.07	2.81	24.23
M_1F_4	65.11	1.72	102.41	5.39	89.30
M_1F_5	57.69	1.90	71.98	4.76	75.99
M_1F_6	48.55	1.99	80.69	4.80	70.13
M_2F_1	49.28	1.91	69.17	4.24	67.66
M_2F_2	65.31	2.76	90.06	4.81	70.73
M_2F_3	51.47	2.47	67.26	4.07	62.38
M_2F_4	72.14	3.24	96.68	5.70	87.44
M_2F_5	67.88	2.66	97.51	6.22	105.7
M_2F_6	70.73	2.30	94.48	6.20	100.9
Treatment mean	59.82	2.20	82.08	4.91	70.86
Controls					
CF	16.52	1.20	28.34	0.97	24.48
CS	21.17	1.14	35.42	1.53	37.67
Control mean	18.85	1.17	31.88	1.25	31.07
SE					
M	1.81	0.19	4.96	0.19	4.43
F	3.14	0.33	8.60	0.33	7.68
MF	4.44	0.47	12.16	0.47	10.87
CD (0.05)					
M	3.91	0.41	NS	0.41	9.58
F	6.78	NS	18.59	0.72	16.60
MF	9.59	NS	NS	1.02	NS
Treatment Vs Control	12.52	1.33	34.17	1.34	NS
Between controls	NS	NS	NS	NS	23.48
Between treatments (including control)	9.59	1.02	26.29	1.02	NS

Table 29. Soil nutrient status (kg ha^{-1}) as influenced by methods of irrigation and levels of fertigation

Treatments	N	P	K	Mg	B
Methods of irrigation					
M_1	301.23	43.38	74.55	54.55	4.11
M_2	297.21	47.14	84.77	52.83	4.45
Fertigation					
F_1	305.71	47.64	80.84	48.92	2.29
F_2	286.23	37.83	82.48	52.25	3.06
F_3	301.46	44.30	78.11	52.42	3.89
F_4	295.79	49.11	77.40	47.51	3.48
F_5	307.13	43.79	73.98	61.24	6.49
F_6	298.98	48.92	85.15	59.82	6.48
Interaction effects					
M_1F_1	307.48	45.65	76.31	51.82	1.97
M_1F_2	294.02	38.60	79.00	53.52	2.55
M_1F_3	305.36	41.80	75.34	57.96	4.10
M_1F_4	296.15	45.14	73.62	43.20	2.97
M_1F_5	309.61	44.62	65.85	61.20	6.71
M_1F_6	294.73	44.49	77.20	59.63	6.38
M_2F_1	303.94	49.62	85.38	46.03	2.61
M_2F_2	278.44	37.06	85.96	50.98	3.57
M_2F_3	297.57	46.80	80.88	46.89	3.67
M_2F_4	295.44	53.09	81.17	51.82	3.99
M_2F_5	304.65	42.96	82.11	61.28	6.27
M_2F_6	303.23	53.34	93.11	60.00	6.59
Treatment mean	315.63	45.26	79.66	53.69	4.28
Controls					
CF	319.53	45.39	20.83	36.28	3.32
CS	311.74	57.32	21.50	33.26	2.81
Control mean	299.22	51.36	21.16	34.77	3.07
SE					
M	3.05	2.52	2.02	1.27	0.09
F	5.29	4.37	3.50	2.20	0.15
MF	7.48	6.18	4.95	3.11	0.22
CD (0.05)					
M	NS	NS	4.37	NS	0.19
F	11.44	NS	NS	4.76	0.33
MF	NS	NS	NS	6.73	0.47
Treatment Vs Control	21.12	NS	13.97	8.79	0.62
Between controls	NS	NS	NS	NS	0.47
Between treatments (including control)	16.18	NS	10.70	6.73	0.47

4.13. UPTAKE OF PLANT NUTRIENTS

Total uptake of plant nutrients namely N, P, K, Mg and B estimated at 15 MAP are depicted in the Table 28.

Methods of irrigation increased the uptake of all nutrients except K. Between the two methods of irrigation, drip irrigation was found advantageous for enhancing N, P, Mg and B uptake. Levels of fertigation also improved the uptake of all the nutrients except P. F_2 on par with F_4, F_4 on par with F_2, F_6 and F_5; F_4 on par with F_6, F_5 and F_2; F_5 on par with F_4 and F_6 resulted in significant increase in the uptake of N, K, Mg and B respectively. Among the different treatment combinations M_1F_2 on par with M_2F_4, M_2F_6 and M_2F_5; and M_2F_5 on par with M_2F_6, M_1F_2, M_2F_4 and M_1F_4 significantly improved the uptake of N and Mg. The control treatment didn't influence the uptake of N, P, K and Mg. However significant improvement in boron uptake was observed with CS. N, P, K and Mg uptake were found to be appreciably influenced by the interaction effects of different treatment combinations including control. The combination M_1F_2 on par with M_2F_4, M_2F_6 and M_2F_5; M_2F_4 on par with M_2F_2, M_2F_5, M_1F_3, M_1F_1 and M_1F_5; M_1F_4 on par with M_2F_5, M_2F_4, M_1F_2, M_2F_6, M_2F_2 and M_1F_6; and M_2F_5 on par with M_2F_6, M_1F_2 M_2F_4 and M_1F_4 significantly enhanced the uptake of N, P, K and Mg.

4.14. SOIL NUTRIENT STATUS AFTER THE EXPERIMENT

The main and interaction effects of treatments including control on N, P, K, Mg and B status of soil after the experiment are depicted in Table 29. Potassium and boron status of soil alone were found to be significantly influenced by the methods of irrigation and in both the cases drip irrigation registered higher status compared to microsprinkler method of irrigation. Levels of fertigation showed its significance on N, Mg and B concentrations and F_5 in all the three cases registered higher values. Mg and B concentrations of soil alone were found to be significantly influenced by the interaction effect of different treatment combinations. M_2F_5 on par with M_1F_5, M_2F_6, M_1F_6 and M_1F_3; and M_1F_5 on par

Table 30 Number of phosphate solubilizing microorganisms (cfu per g of soil) as influenced by methods of irrigation and levels of fertigation

Treatments	10^3 cfu g^{-1}	10^4 cfu g^{-1}	10^5 cfu g^{-1}
Methods of irrigation			
M_1	1 58	2 41	1 91
M_2	2 00	2 66	2 08
Fertigation			
F_1	1 25	2 75	1 00
F_2	2 00	3 50	3 00
F_3	1 50	1 75	3 25
F_4	3 00	3 25	1 50
F_5	1 50	2 00	2 25
F_6	1 50	2 00	1 00
Interaction effects			
M_1F_1	1 00	3 50	1 00
M_1F_2	1 50	4 00	4 00
M_1F_3	1 00	1 50	3 00
M_1F_4	3 50	3 00	1 50
M_1F_5	1 00	1 50	1 00
M_1F_6	1 50	1 00	1 00
M_2F_1	1 50	2 00	1 00
M_2F_2	2 50	3 00	2 00
M_2F_3	2 00	2 00	3 50
M_2F_4	2 50	3 50	1 50
M_2F_5	2 00	2 50	3 50
M_2F_6	1 50	3 00	1 00
Treatment mean	1 79	2 54	2 00
Controls			
CF	4 00	3 00	2 50
CS	9 00	5 50	3 50
Control mean	6 50	4 25	3 00
SE			
M	0 34	0 33	0 49
F	0 60	0 57	0 85
MF	0 85	0 81	1 20
CD (0 05)			
M	NS	NS	NS
F	NS	1 25	NS
MF	NS	NS	NS
Treatment Vs Control	2 40	2 30	NS
Between controls	1 84	1 76	NS
Between treatments (including control)	1 84	1 76	NS

cfu colony forming unit

with M_2F_6, M_1F_6, and M_2F_5 significantly increased the Mg and B content of the soil respectively after the experiment The effect of two control treatments was evident in influencing boron concentration only and CF reported higher value compared to CS The effect of treatment combination including control significantly and positively influenced the N, K, Mg and B content of the soil after the experiment CF on par with CS, M_1F_5, M_1F_1, M_1F_3, M_2F_5 and M_2F_1, M_2F_6 on par with M_2F_2 and M_2F_1, M_2F_5 on par with M_1F_3, M_2F_6, M_1F_6 and M_1F_3, and M_1F_5 on par with M_2F_6, M_1F_6, and M_2F_5 registered significantly higher concentrations of N, K, Mg and B respectively after the experiment

4 15 PHOSPHOROUS SOLUBILIZING MICRO ORGANISMS

The main and interaction effects of treatment combinations including control on the population of phosphate solubilizing microorganisms at 15 MAP are furnished in Table 30 The population of phosphate solubilizing microorganisms were not at all influenced by the methods of irrigation however in drip irrigation increased population was observed at all dilutions Levels of fertigation significantly influenced the population of phosphate solubilizing microorganisms only at dilution 10^4 F_2 on par with F_4 and F_1 registered significantly higher population Interaction effects of treatment combinations didn't significantly influence the population of microorganisms at any of the dilutions that is 10^3, 10^4 and 10^5 tried The effect of control treatments on population of phosphate solubilizing microorganisms was remarkable at dilutions of 10^3 and 10^4 cfu per gram of soil The population was also significantly influenced by interaction effect of different treatment combinations including control CS at 10^3 dilution and CS on par with M_1F_2 at 10^4 dilution recorded significantly higher population levels

4 16 SOIL MOISTURE STUDIES

Mean data on soil moisture content after and before irrigation, seasonal consumptive use, mean daily consumptive use, crop water use efficiency, crop coefficient (Kc), field water use efficiency and water productivity as influenced by main and interaction effects of different treatment combinations are furnished in Table 31

The main and interaction effects of different treatment combinations had no significant influence on soil moisture content before and after irrigation, seasonal consumptive use and mean daily consumptive use Similarly, the control treatments didn't significantly influence any of the aforesaid parameters However positive and significant influence of treatments including control was observed for all the above parameters M_2F_6, M_1F_3, CS and CS registered the highest soil moisture content after irrigation, soil moisture content before irrigation, seasonal consumptive use and mean daily consumptive use respectively The seasonal consumptive use and mean daily consumptive use values were higher when long pepper was raised as intercrop in the open interspaces Crop water use efficiency and field water use efficiency were found to be significantly influenced by the interaction effects of different treatment combinations including control Between the methods of irrigation microsprinkler recorded significantly higher CWUE which was 69 50 per cent higher over drip system The trend was also similar with respect to FWUE as well Levels of fertigation also remarkably influenced the CWUE and F_3 recorded highest CWUE of 65 97 g m^{-3} A similar trend was observed in case of FWUE as well Among the interaction effects M_1F_3 recorded the highest CWUE which was significantly different from all other treatment combinations The same treatment combination recorded the highest FWUE of 36 32 g m^3 (M_1F_3) which was on par with M_1F_6 Control treatments neither significantly influenced CWUE nor FWUE Interaction effects of treatment combinations including control also indicated the significant superior performance of above two treatment combmations with respect to CWUE and FWUE as well The mam effects and interaction effects had no significant effect on crop coefficient However significant influence of treatment

Table 31 Soil moisture as influenced by methods of irrigation and levels of fertigation

Treatments	Mai (%)	Mbi (%)	Seasonal Cu (mm)	Mean daily Cu (mm)	CWUE (gm^{-3})	Kc	FWUE (gm^{-3})	WP (gm^{-3})
Methods of irrigation								
M_1	12 31	8 61	485 90	1 76	53 31	0 62	25 77	519 21
M_2	12 02	8 43	475 62	1 72	31 45	0 61	15 26	599 04
Fertigation								
F_1	11 86	8 40	463 95	1 68	29 00	0 59	13 92	494 60
F_2	12 34	8 19	527 51	1 91	41 31	0 68	21 99	593 84
F_3	11 71	8 89	405 45	1 47	65 97	0 52	27 50	526 22
F_4	12 53	8 79	489 74	1 78	38 59	0 63	18 59	645 97
F_5	11 72	8 45	446 44	1 62	34 69	0 57	16 15	617 25
F_6	12 83	8 42	551 47	2 00	44 73	0 71	24 93	476 87
Interaction effects								
M_1F_1	11 96	8 49	464 87	1 69	31 76	0 60	15 23	468 76
M_1F_2	12 53	8 40	525 67	1 91	54 67	0 67	28 78	674 11
M_1F_3	11 72	8 97	398 54	1 44	88 29	0 51	36 32	484 18
M_1F_4	12 76	8 87	503 56	1 83	43 85	0 65	20 75	627 89
M_1F_5	12 12	8 41	486 98	1 77	38 42	0 62	19 32	475 65
M_1F_6	12 78	8 54	535 81	1 94	62 88	0 69	34 21	384 67
M_2F_1	11 76	8 31	463 03	1 68	26 24	0 59	12 61	520 44
M_2F_2	12 15	7 98	529 36	1 92	27 95	0 68	15 19	513 56
M_2F_3	11 71	8 81	412 36	1 49	43 65	0 53	18 67	568 26
M_2F_4	12 30	8 71	475 92	1 73	33 34	0 61	16 43	664 04
M_2F_5	11 33	8 50	405 91	1 47	30 96	0 52	12 99	758 85
M_2F_6	12 89	8 31	567 13	2 06	26 57	0 73	15 65	569 08
Treatment mean	12 16	8 52	480 76	1 74	42 38	0 62	20 51	559 12

Controls								
CF	10 65	7 34	630 80	2 29	6 93	0 81	4 50	243 34
CS	10 99	7 66	632 65	2 30	4 71	0 81	3 06	256 86
Control mean	10 82	7 50	631 73	2 29	5 82	0 81	3 78	250 10
SE								
M	0 25	0 14	28 74	0 10	3 40	0 037	0 93	35 73
F	0 43	0 24	49 79	0 18	5 90	0 064	1 61	61 89
MF	0 61	0 35	70 41	0 25	8 34	0 091	2 28	87 53
CD (0 05)								
M	NS	NS	NS	NS	7 36	NS	2 01	77 20
F	NS	NS	NS	NS	12 74	NS	3 48	NS
MF	NS	NS	NS	NS	18 03	NS	4 92	NS
Treatment Vs Control	1 73	0 99	198 58	0 72	23 53	0 25	6 43	246 84
Between controls	NS	NS	NS	NS	NS	NS	NS	NS
Between treatments (including control)	1 33	0 76	152 13	0 55	18 03	0 19	4 92	189 10

Table 32 Economics of cultivation as influenced by methods of irrigation and levels of fertigation (Rs ha^{-1})

Treatments	Cost of cultivation	Gross returns	Net returns	BCR
Methods of irrigation				
M_1	87483 33	248976 58	161493 25	2 84
M_2	89883 33	147430 83	57547 50	1 64
Fertigation				
F_1	79150 00	134500 00	55350 00	1 70
F_2	84090 00	212458 75	128368 75	2 53
F_3	85000 00	265654 75	180654 75	3 15
F_4	91290 00	179650 00	88360 00	1 96
F_5	93140 00	156096 25	62956 25	1 68
F_6	99430 00	240862 50	141432 50	2 42
Interaction effects				
M_1F_1	78400 00	147150 00	68750 00	1 87
M_1F_2	83340 00	278110 00	194770 00	3 33
M_1F_3	82900 00	350904 50	268004 50	4 23
M_1F_4	90540 00	200490 00	109950 00	2 21
M_1F_5	91040 00	186667 50	95627 50	2 05
M_1F_6	98680 00	330537 50	231857 50	3 34
M_2F_1	79900 00	121850 00	41950 00	1 52
M_2F_2	84840 00	146807 50	61967 50	1 73
M_2F_3	87100 00	180405 00	93305 00	2 07
M_2F_4	92040 00	158810 00	66770 00	1 72
M_2F_5	95240 00	125525 00	30285 00	1 31
M_2F_6	100180 00	151187 50	51007 50	1 50
Treatment mean	88683 33	198203 70	109520 37	2 24
Controls				
CF	48000 00	43559 00	-4441 00	0 90
CS	48000 00	29570 00	-18430 00	0 61
Control mean	48000 00	36564 50	-11435 50	0 76
SE				
M		8999 41	8999 41	0 10
F		15587 44	15587 44	0 17
MF		22043 98	22043 98	0 24
CD (0 05)				
M		19442 02	19442 02	0 217
F		33674 63	33674 63	0 376
MF		47623 11	47623 11	0 533
Treatment Vs Control		62164 01	62164 01	0 695
Between controls		NS	NS	NS
Between treatments (including control)		47623 11	47623 11	0 533

combinations including control was observed on Kc values and CS followed by CF registered higher values Water productivity was also found to be significantly influenced by methods of irrigation and drip irrigation recorded the water productivity of 599 04 g m^{3} which was 15 37 per cent higher compared to microsprinkler Levels of fertigation and interaction effects of different treatment combinations didn't significantly influence water productivity The two control treatments were also insignificant in influencing water productivity However the treatment combinations including control significantly influenced water productivity and highest water productivity of 758 85 g m^{-3} was recorded in the treatment combination M_2F_5 which was on par with M_1F_2, M_2F_4 and M_2F_6 and 203 41per cent higher compared to control mean

4 17 ECONOMIC ANALYSIS OF THE SYSTEM

The mean data on cost of cultivation, gross returns, net returns and benefit cost ratio as influenced by the main and interaction effects including control are depicted in Table 32

Microsprinkler method of irrigation recorded significantly higher gross returns, net returns and BCR of Rs 2 48 lakh, Rs 1 61 lakh and 2 84 when compared to drip irrigation the per cent increase were 68 87, 180 62 and 73 17 respectively Gross returns, net returns and BCR were also significantly influenced by levels of fertigation and F_3 in all the three cases registered higher values of Rs 2 65 lakh, Rs 1 80 lakh and 3 15 respectively Interaction effects also indicated significant improvement of gross returns, net returns and BCR on integration of microsprinkler and water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas However the two control treatments had no significant effect on any of the economic parameters studied The effect of treatment combinations including control also contributed to higher returns and M_1F_3 on par with M_1F_6 M_1F_3 on par with M_1F_6 and M_1F_3 recorded significantly higher gross returns, net returns and BCR to the tune of Rs 3 50 lakh, Rs 2 68 lakh and 4 23 respectively

DISCUSSION

5. DISCUSSION

The result of the experiment presented in the previous chapter are discussed below

5 1 GROWTH CHARACTERS

Methods of irrigation *viz*, microsprinkler and drip significantly influenced growth characters of long pepper at final harvest i e , 15 MAP In general, drip irrigation was found beneficial in enhancing vine length, leaf number and number of branches compared to microsprinkler and the per cent increase were 17 02, 11 76 and 10 15 respectively (Tables 6, 7, 9 and Fig 3, 4, 6) However LAI was found to be significantly improved by the microsprinkler compared to drip irrigation (Table 8 and Fig 5) The effect of fertigation was not consistent at any of the growth stages F_5, F_3 followed by F_1, F_2 and F_1 followed by F_3 recorded higher values of vine length, leaf number, leaf area index and number of branches at final harvest Integration of two factors *viz*, methods of irrigation and fertigation were found remarkable in influencing all the growth characters and the treatment combinations *viz*, M_2F_5, M_2F_1, M_1F_2 and M_2F_3 recorded higher values of vine length, leaf number, LAI and number of branches at 15 MAP Treatment mean showed its superiority over control mean with respect to all growth characters studied

Morphological characters *viz*, vine length, leaf number, number of branches indicate the photosynthetic capacity of long pepper and transpirational area in relation to water productivity Crop growth is influenced by metabolic activities which need sufficient amounts of plant nutrients and water besides a favourable micro climate Both the drip and microsprinkler methods of irrigation provided sufficient amount of moisture in the root zone (Table 31) to meet crop water requirements compared to the control treatments where the crop was planted outside the poly cum shade house but in the open interspaces of properly spaced

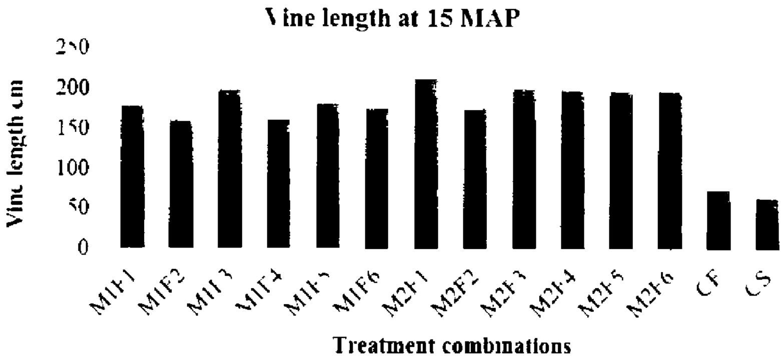


Fig 3 Vine length (cm) as influenced by methods of irrigation and levels of fertigation

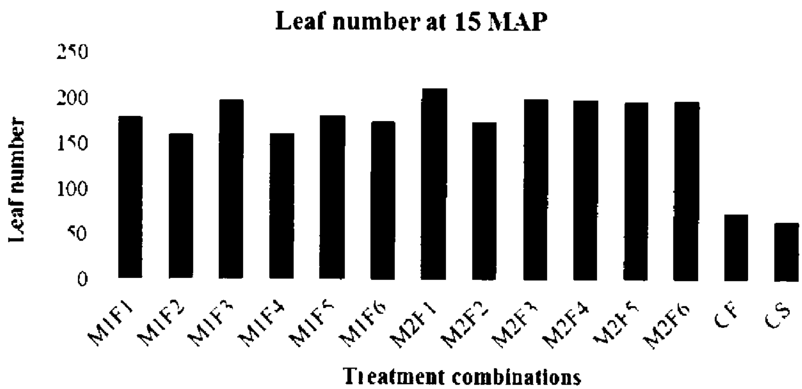


Fig 4 Leaf number as influenced by methods of irrigation and levels of fertigation

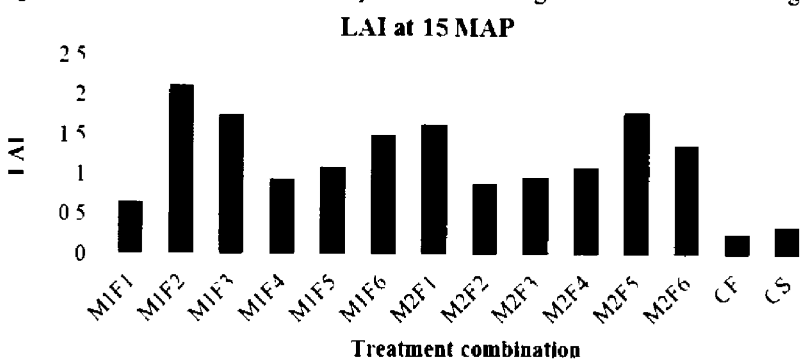


Fig 5 Leaf area index as influenced by methods of irrigation and levels of fertigation

coconut palms. Wide variations in wetting pattern were observed with respect to methods of irrigation. Microsprinkler method of irrigation resulted in total wetting of plant surface where as in drip irrigation the movement of water was from a dripper point source. It wets in a horizontal circular direction on the soil surface and also vertically down the soil profile. Hence the soil moisture content is not uniform in rhizosphere facilitating oxygen exchange for intensive root growth. Thus rhizosphere maintained favourable moisture-nutrient balance for better absorption of water and nutrients compared to flood irrigation practiced in control treatments. This favourable balance might have led to growth enhancement in long pepper under micro irrigation compared to flood irrigation. Modification of the micro climate where fertigation was given through microsprinkler irrigation which is evident from micro climatic parameters (Tables 17, 18 and 19) might have facilitated the leaf to expand further resulting in higher leaf area index. Intercropping long pepper in properly spaced coconut palms (7.5m x 7.5m) without artificial shade resulted in very poor vegetative growth as the microclimatic parameters were hostile for vigorous growth of long pepper. It need favourable microclimatic conditions for uninterrupted vigorous growth. The climatic requirements of long pepper have been reported by several workers. Long pepper is a crop which requires shade for its optimum growth. It is a semi shade loving crop and flourishes well under tropical rainforest. Exposure to sunlight causes scorching and yellowing there by reduces growth and yield. So, shade management is essential for obtaining a good crop stand. Micro climatic conditions inside a coconut garden is suitable for the cultivation of long pepper. Poly cum shade house erected in the interspaces of coconut garden can be used for commercial cultivation of long pepper (Jayanth *et al.,* 2015). Height of plant, collar diameter, number of leaves per plant and leaf chlorophyll content were found to be higher in long pepper grown under medium shade (50 per cent shade) compared to low (25 per cent shade) and deep shade (75 per cent shade). Reason for reduced growth and yield of long pepper plants under full sunlight was due to photo oxidation of chlorophyll pigments (Etampawala *et al.,* 2002).

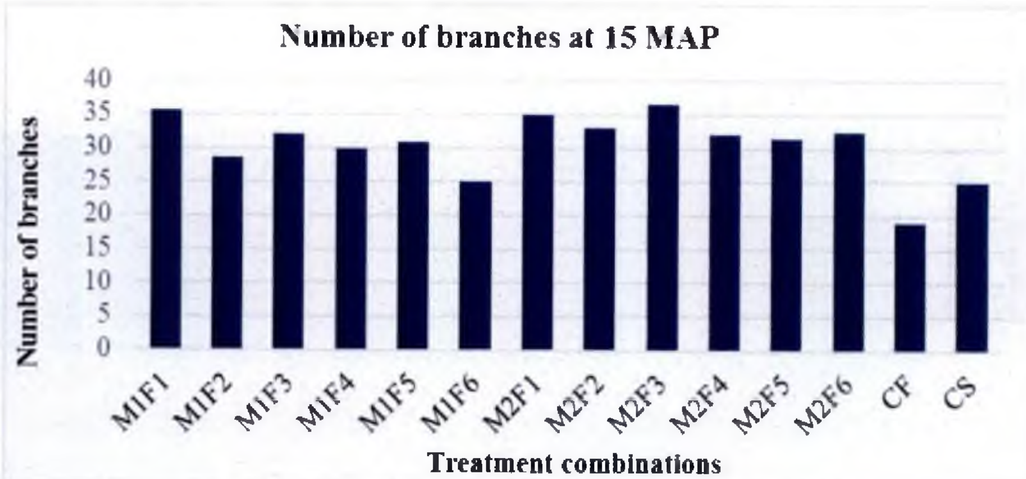


Fig 6. Number of branches as influenced by methods of irrigation and levels of fertigation

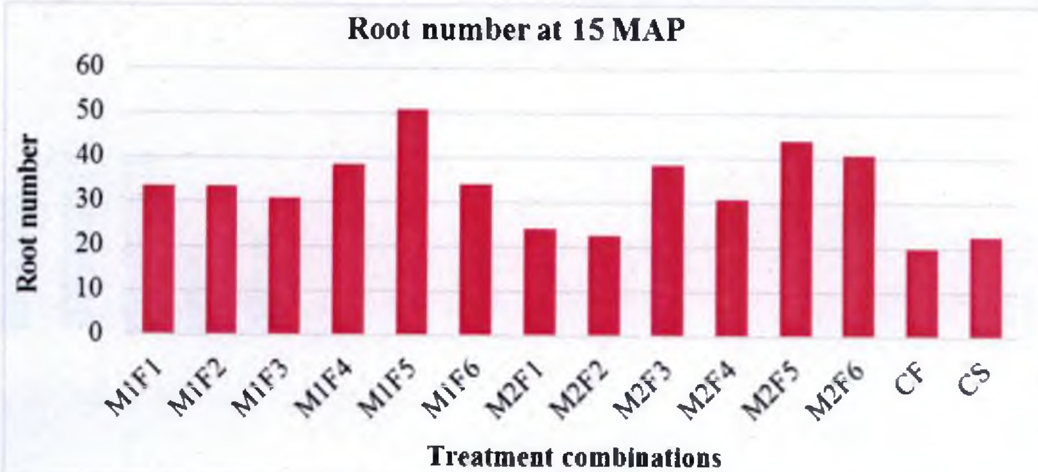


Fig 7. Root number as influenced by methods of irrigation and levels of fertigation

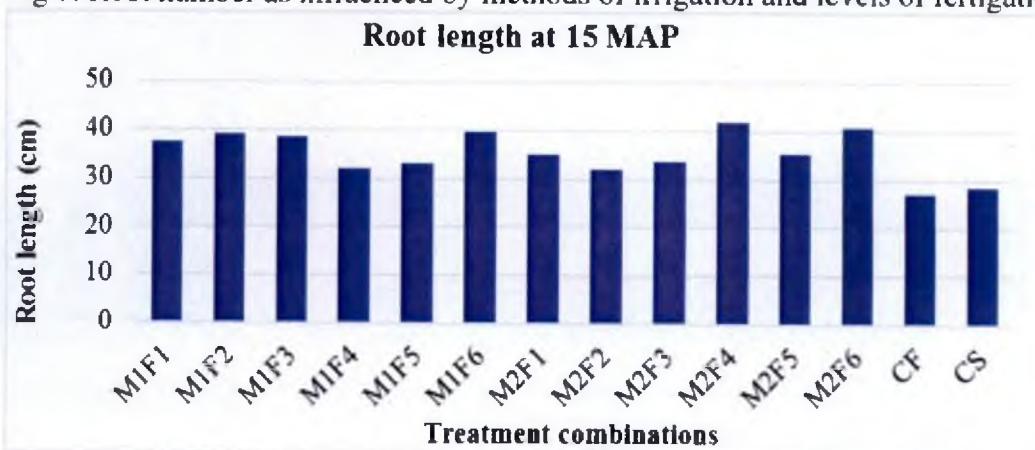


Fig.8 Root length (cm) as influenced by methods of irrigation and levels of fertigation

Fertigation provides an excellent opportunity for the vigorous growth of plants on account of improved nutrient availability, enhanced plan nutrient uptake, reduced fertilizer application rates, water requirements, minimum loss of nutrients through leaching, preventing salt injuries to roots and foliage, reduced compaction because of the reduced surface traffic and decreasing weed infestation. Cultivation in poly cum shade house has added advantage of reduced soil evaporation compared to open interspaces. The above factors might have contributed to better vegetative growth of long pepper.

5.2. ROOT CHARACTERS

At 15 MAP, microsprinkler was found beneficial for improving root number and root length to the tune of 10.17 and 0.74 per cent (Tables 10 and 11 and Fig 7 and 8) compared to drip irrigation. However drip irrigation enhanced root spread and root weight which where 1.27 and 16.58 per cent higher over micro sprinkler irrigation (Tables 12 and 13 and Fig 9 and 10). Though the effect of fertigation was found inconsistent in influencing root number, root length, root weight and root spread, F_5, F_6, F_4 and F_2 recorded higher values compared to other levels. The effect of treatment combinations on root parameters were significant and M_1F_5 on par with M_2F_5, M_2F_4, M_2F_4 and M_1F_2 recorded significantly higher values. In general, the treatment mean showed its significance over all the root characters studied. The root distribution pattern of crops is mainly influenced by the movement of water and nutrients in the soil which varies widely with situations. It is reported that in saturated soil the root spread is minimum just below the point of delivery of water from the emitter probably due to higher concentration of nutrients and lack of oxygen. Live roots are abundant and active in the rhizosphere where there exists equilibrium among moisture, nutrients and oxygen. Combined application of water soluble NPK + PGPR Mix- I + Fluorescent pseudomonas + Mg + B resulted in an extensive development of root system due to various factors. The growing medium physically supports and

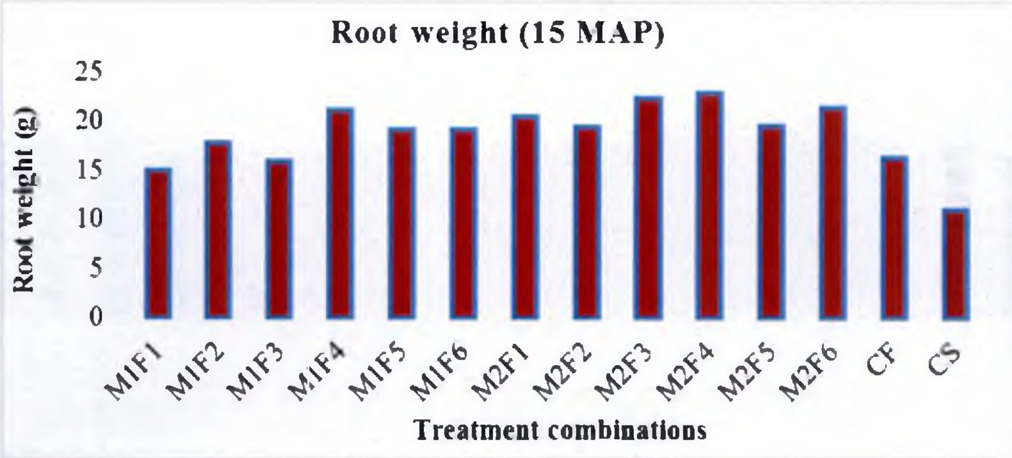


Fig 9. Root weight (g) as influenced by methods of irrigation and levels of fertigation

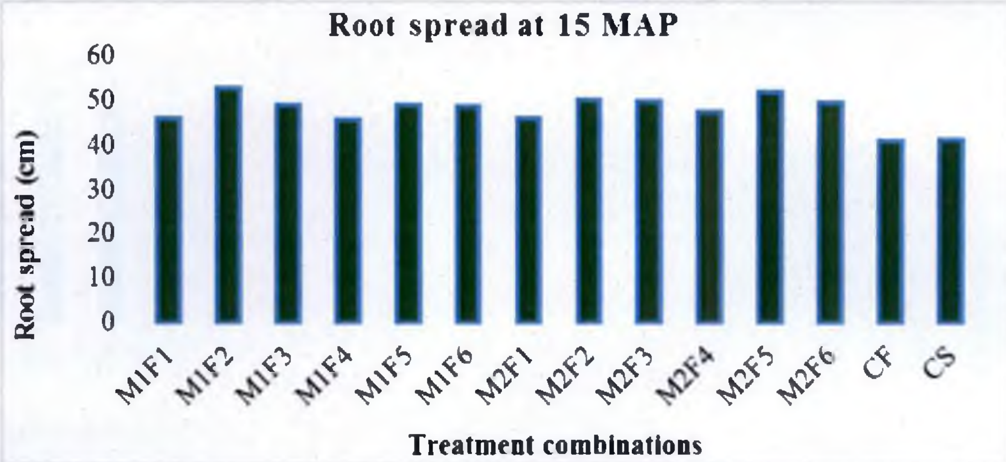


Fig 10. Root spread (cm) as influenced by methods of irrigation and levels of fertigation

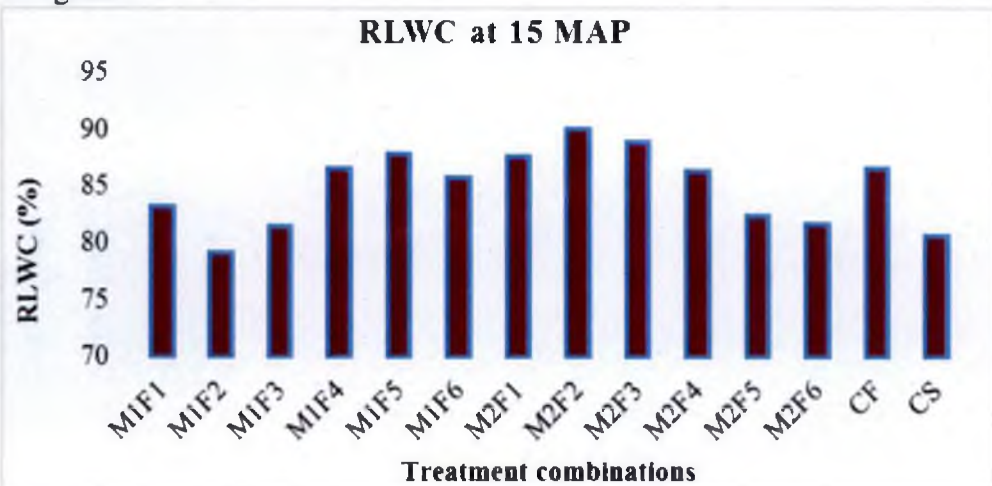


Fig 11. Relative leaf water content as influenced by methods of irrigation and levels of fertigation

supplies water, nutrients and oxygen to the root system. The better medium, better will be the development of root system and healthy establishment of plant. A proper blend of water soluble NPK + PGPR Mix- I + Fluorescent pseudomonas + Mg + B constituted an effective medium for efficient root growth. The characteristics of inputs used to enrich the rhizosphere are worth mentioning in this context as that have several advantages in root growth and subsequent plant development. Application of primary, secondary and micronutrients are essential for better root development. Bijilykrishnan (2003) reported the beneficial effects of major nutrients in root development of long pepper. Application of PGPR Mix- I, generates and supplies sufficient quantities of different phytohormones, organic acids and siderophore which improves growth of plants. Apart from this they have a capacity to fix nitrogen, solubilizing phosphorous and produces plant growth regulators that can positively influence plant growth (Prathap and Kumari, 2015). *Pseudomonas fluorescence* have a capacity to improve plant growth and nutrient uptake by producing certain growth promoting substances and secondary metabolites (Burr *et al.,* 1978). They are also capable of producing antibiotics, phytohormones, volatile compounds, indole-3-acetic acid and siderophore which promote the growth and resistance mechanism of crops (Sivasakthi *et al.,* 2014). Pseudomonas is capable of directly promoting the growth of plants by producing phytohormones and solubilizing phosphorous.

5.3. PHYSIOLOGICAL PARAMETERS

Among the different physiological parameters *viz,* relative leaf water content, stomatal conductance, transpiration rate and SPAD meter readings, none of the parameter showed significance due to treatment effects. However, drip irrigation resulted in higher RLWC and leaf temperature whereas microsprinkler enhanced stomatal conductance, transpiration rate and SPAD meter reading (Tables 14 to 18). Similar to root characters and growth parameters, levels of fertigation were inconsistent in influencing different physiological parameters studied. However F_4, F_5, F_5, F_3 and F_6 showed their superiority in influencing RLWC, stomatal conductance, transpiration rate, leaf temperature and SPAD

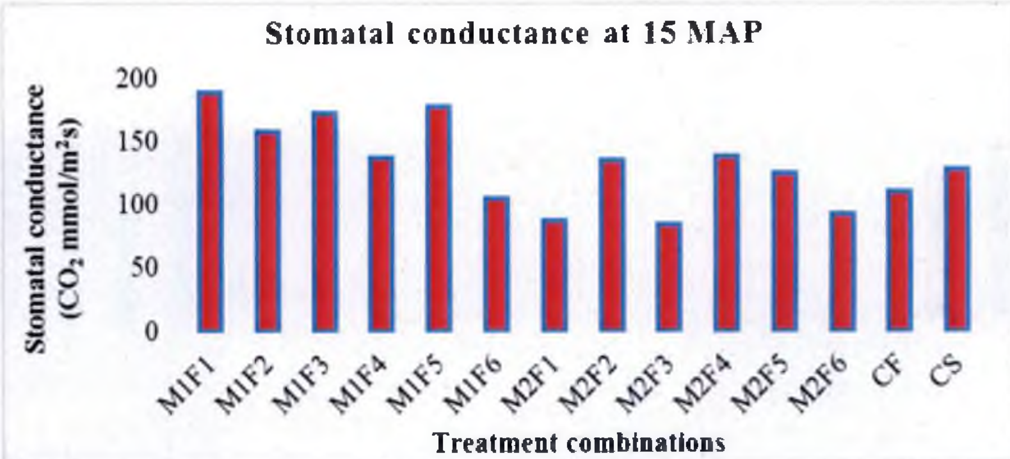


Fig 12. Stomatal conductance (CO_2 mmol/m^2s) as influenced by methods of irrigation and levels of fertigation

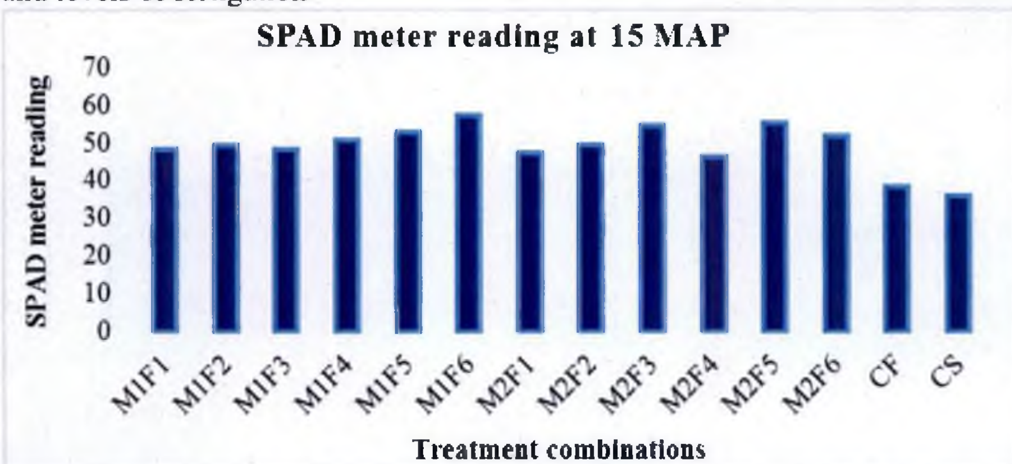


Fig 13. SPAD meter reading as influenced by methods of irrigation and levels of fertigation

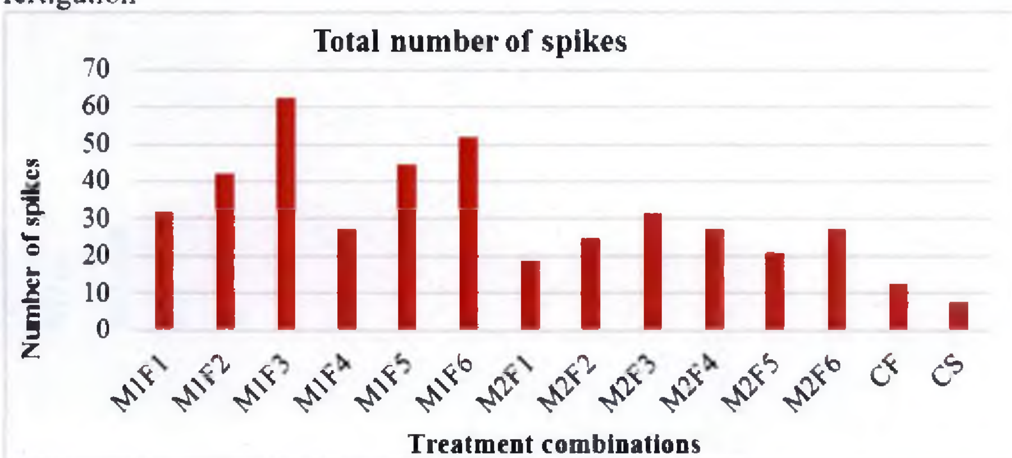


Fig 14. Total number of spikes (per plant) as influenced by methods of irrigation and levels of fertigation

meter reading respectively (Tables 14 to 18). The treatment combinations were non significant in influencing physiological parameters.

Relative leaf water content is important indicator for plant water status. The relationship between RLWC and water potential differs with species. Under stress condition, a species with higher RLWC indicates that it is more drought resistant. Studies have shown that maximum RLWC is useful for differentiate between drought resistant and drought susceptible cultivars. A species with higher RLWC at water potential of 1.5 mpa is more drought resistant. Modification of microclimatic parameters by micro irrigation methods and poly cum shade house might have contributed to wide variations in physiological parameters studied. Comparison of treatment mean and control mean indicates the higher RLWC in all treatments that are maintained under poly cum shade house because of the lower transpiration rate which is evident from the canopy temperature data furnished in Tables 17 and 18. In general, canopy temperature and transpiration were higher when long pepper was raised in the open interspaces which received more total solar radiation and PAR compared to poly cum shade house (Table 17, 18 and 19). The above results are in line with the findings of Leopold *et al.* (1981). The percentage electrolyte leakage was highest (less membrane integrity) under open field condition in Kohinoor and lowest under 35 per cent 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. Similar result was observed by Kavitha (2005) in tomato. The reduction in relative leaf 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). The crop received more solar radiation and PAR when intercropped in the open interspaces of coconut garden under unprotected condition compared to cultivation in poly cum shade house. The UV stabilized polythene sheets mulched over the shade nets (50 per cent shade) reduced availability of both total

Plate 2. Crop growth at different stages

a. 3 Months after planting

b. 6 Months after planting

c. 9 Months after planting

d. 11 Months after planting

e. 13 Months after planting

f. 15 Months after planting

solar radiation and PAR under poly cum shade house.

5.4. SPIKE NUMBER AND SPIKE YIELD

Yield components and yield of long pepper were found to be significantly influenced by treatment effects. The crop responded favourably to microsprinkler irrigation and the increase in total number of spikes per plant, total fresh spike production per plant, total dry spike production per plant, total fresh spike yield per hectare and total dry spike yield per hectare were 71, 76, 68, 76 and 68 per cent respectively over drip irrigation (Tables 20,21,22,23 and 24). The effect of levels of fertigation on yield components and yield of long pepper was evident and combined application of water soluble NPK + PGPR mix- I + Fluorescent pseudomonas significantly increased total number of spikes per plant, total fresh spike yield per plant, total dry spike yield per plant, fresh spike yield per hectare and dry spike yield per hectare and the increase over control mean were 525, 635, 632, 635 and 632 respectively (Tables 20,21,22,23 and 24). Discharging water soluble NPK + PGPR Mix- I + Fluorescent pseudomonas through microsprinkler irrigation significantly improved yield components and yield of long pepper (Fig 14 to 18). Among the treatment combinations including control the total number of spikes per plant ranged from 7.50 to 62.50 and the highest number was observed in M_1F_3 which was 525 per cent more compared to control mean (Table 20 and Fig 14). Total fresh and dry spike yield per plant ranged from 3.21 g to 37.68 g and 0.47 g to 5.61 g (M_1F_3) and the per cent increase over control mean was 858 and 867 respectively (Tables 21, 22 and Fig 15,16).

The spike number per plant is an important yield attribute in determining yield. Long pepper requires heavy manuring for its growth and production. Spike production is influenced by the metabolic activities which requires adequate amounts of nutrients and moisture. Biometric characters, root parameters and physiological parameters indicate that long pepper crop responds very well to cultural inputs and agro climatic situations.

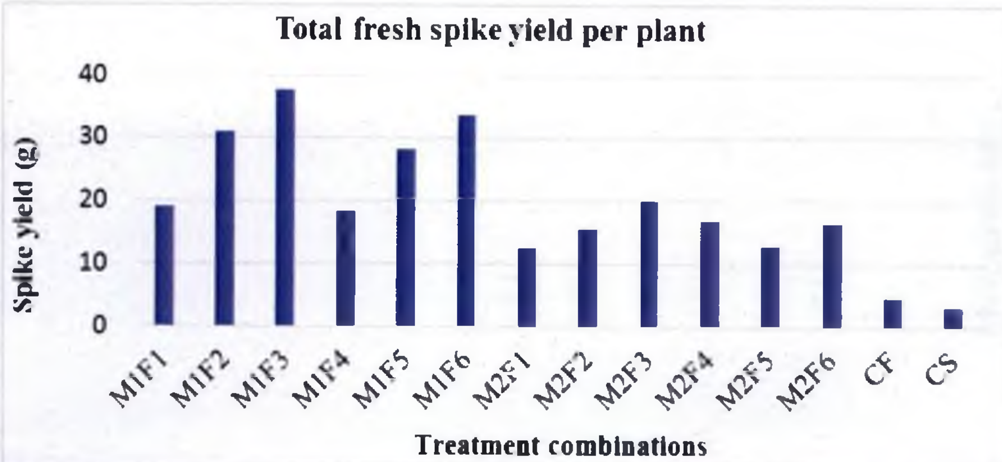


Fig 15. Total fresh spike yield per plant (g) as influenced methods of irrigation and levels of fertigation

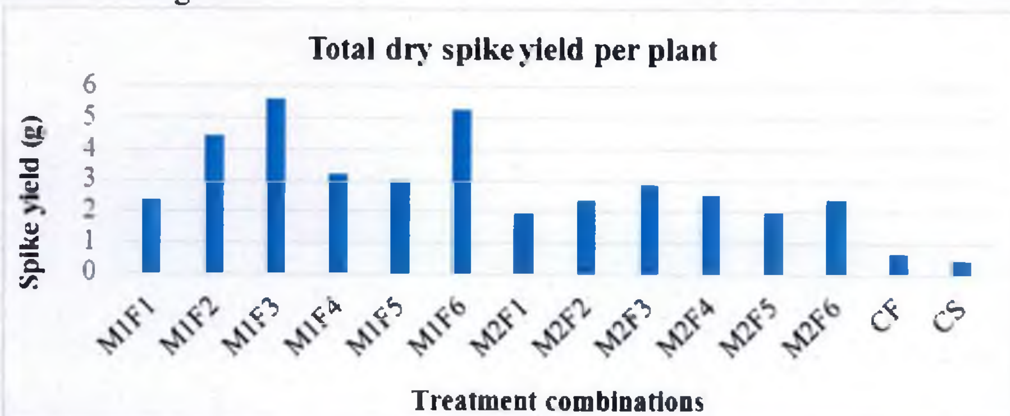


Fig 16. Total dry spike yield per plant (g) as influenced by methods of irrigation and levels of fertigation

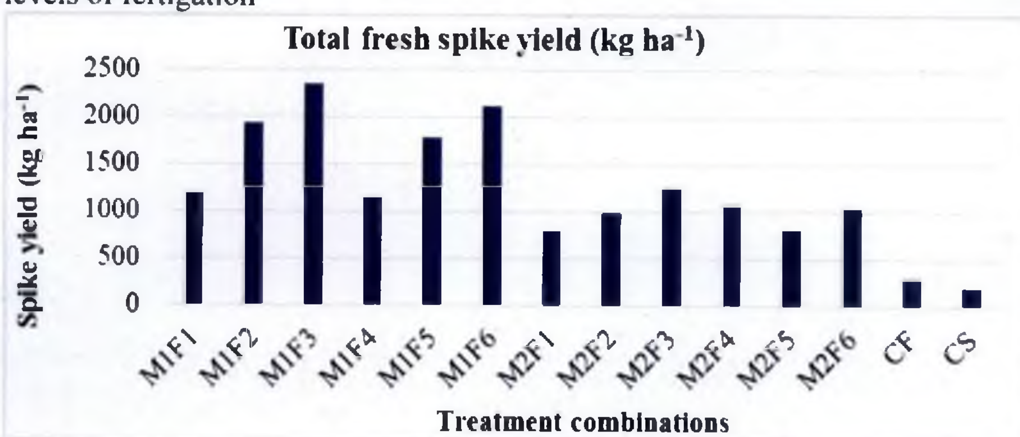


Fig 17. Total fresh spike yield (kg ha^{-1}) as influenced by methods of irrigation and levels of fertigation

Sprinkler irrigation maintained ideal microclimatic parameters inside the poly cum shade house for higher spike number and spike yield. Spraying minute water droplets in to air through microsprinkler heads rather than discharging water drop by drop through emitter at zero pressure modified the microclimate for vigorous growth and extensive root system. Microsprinkler irrigation contributed substantially for leaf area expansion there by increasing photosynthetic area and production of more number of roots which was evident from Table 8 and 10. Stomatal conductance, transpiration rate, SPAD meter reading were also substantially improved in sprinkler irrigation compared to drip irrigation which might have contributed to higher spike number and spike production (Tables 15, 16 and 18). The reasons attributed for higher values of all above parameters discussed under section 5.1, 5.2 and 5.3 are applicable for higher spike number also. Apart from this, the beneficial effect of foliar application method may be attributed to the increased dry spike yield. Increased uptake of nutrients through foliar application and their rapid utilization leads to the activated metabolism of plants (Chaudhuri and De, 1975). This may also contribute to increase in number of spikes and yield. The findings of present study are in line with the findings of Prabhakar *et al.* (2011).

5.5. TOTAL DRYMATTER PRODUCTION

Drip irrigation was found to enhance dry matter production per plant and the per cent increase over microsprinkler was 9.36 per cent. Liquid organic manures on par with liquid organic manures + PGPR Mix- I + Fluorescent pseudomonas was found favourable for enhancing total dry matter production per plant. Total dry matter production ranges from 25.15 g to 57.91 g (Table 25). Among the different treatment combinations including control M_1F_2 registered higher total dry matter production per plant confirming the superiority of liquid organic manures in enhancing total dry matter production per plant and the per cent increase over control mean was 124 (Fig 19). Treatment mean recorded spectacular increase in dry matter production which was 75 per cent higher over control mean.

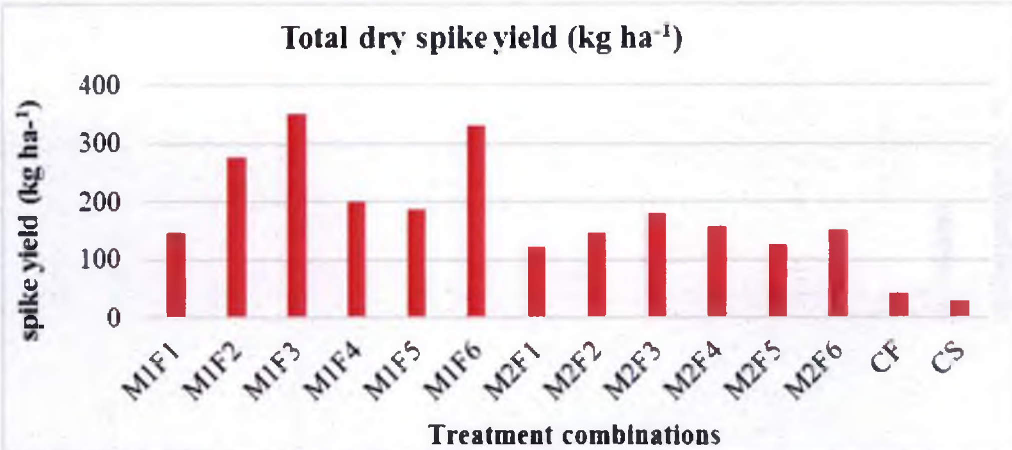


Fig 18. Total dry spike yield (kg ha^{-1}) as influenced by methods of irrigation and levels of fertigation

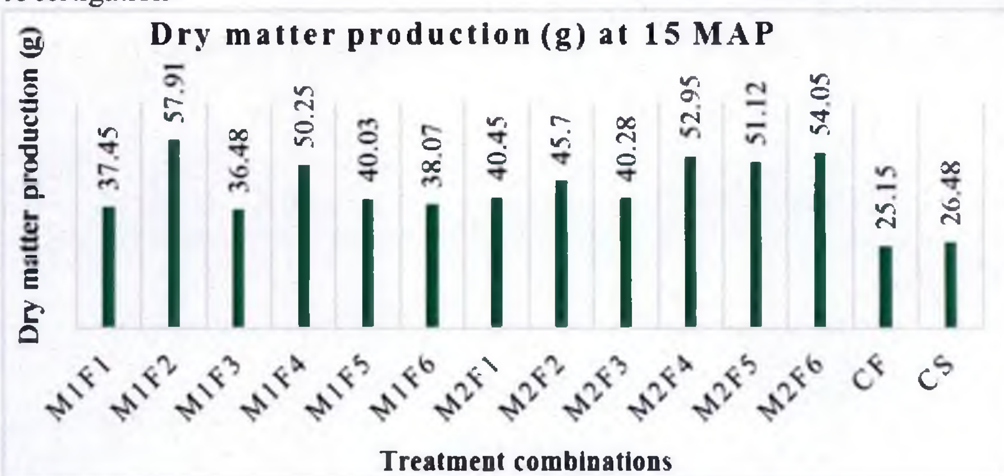


Fig 19. Dry matter production per plant (g) as influenced by methods of irrigation and levels of fertigation

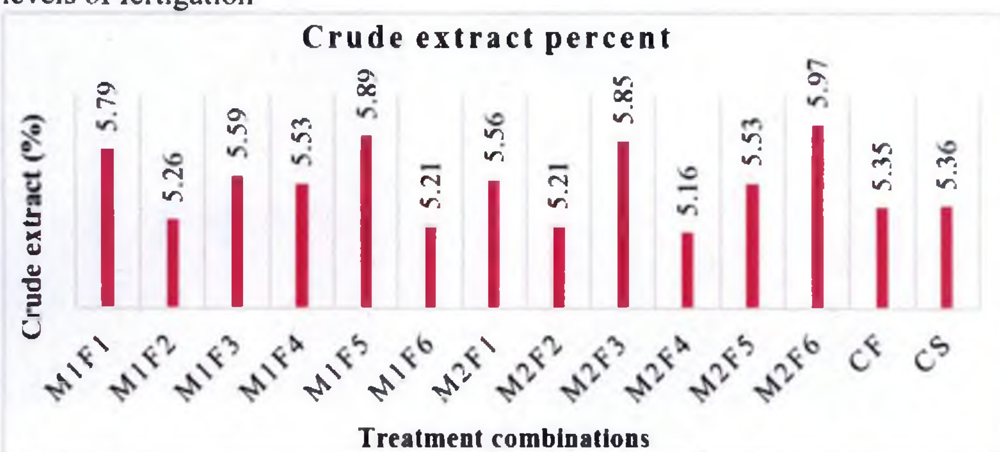


Fig 20. Crude extract per cent as influenced by methods of irrigation and levels of fertigation

There was considerable reduction in total dry matter production when long pepper was intercropped in open condition in coconut garden due to higher total solar radiation, PAR, canopy temperature resulting in rapid depletion of moisture. Water deficits have a negative effect on dry matter production in crops as it effects any of the metabolic process related with crops. The reduction in dry matter production could be attributed to decrease in plant characters like vine length, leaf number, LAI and spike number. On the other hand cultivation in poly cum shade house enhanced total dry matter production. The shade nets covered with UV stabilized polythene sheets moderated both diurnal and seasonal variations in temperature of both soil and air. Poly cum shade house reduced the midday maximum temperature under hot and dry conditions.

Rotational application of vermiwash, cow urine and fermented plant juice (F_2) considerably enhanced total dry matter obviously because of the direct and indirect effects. Vermiwash contains excretory products and mucous secretions of earthworms along with nutrients from soil organic molecules. Vermiwash is rich in nutrients and plant hormones which enhances the growth of plants (Rekha *et al.*, 2013). Slow nutrient release along with plant hormones like gibberellin, cytokinin and auxin present in these manures causes improved yield of crops (Ansari, 2008). Presence of hormones like auxin in cow urine stimulates the growth of plants (Oliveira *et al.*, 2009). Fermented plant juice is fermented extract of plant cell sap and extracts. It is a rich enzyme solution full of bacteria dominated by lactic acid bacteria and yeast and is used for invigorating plants. Rotational application of these liquid manures supplied substantial quantities of major, secondary and micro nutrients besides hormones, enzymes etc. needed for the above and below ground growth of long pepper which contributed substantially for increasing total dry matter production.

5.6. QUALITY ATTRIBUTES

The crude extract content ranged from 5.16 to 5.97 per cent. Though the method of irrigation didn't significantly influence the crude extract per cent of long pepper, total crude extract production was remarkably influenced and microsprinkler irrigation resulted in highest crude extract production of 13.70 kg ha^{-1} which was 67 per cent higher compared to drip (Table 26). Levels of fertigation influenced both crude extract per cent and production per unit area and application of water soluble NPK along with PGPR Mix- I + Fluorescent pseudomonas (F_3) resulted in higher content and production of crude extract (Table 26). Among the treatments including control, crude extract per cent and crude extract production ranged from 5.16 to 5.97 per cent and 1.58 to 19.65 kg ha^{-1} respectively (Table 26). The treatment combination M_1F_3 and M_2F_6 recorded higher total crude extract production and the per cent increase over control mean were 902 and 779 (Fig 20 and 21). The dried spike which contains more than twenty alkaloids *viz,* piperine, methyl piperine, iperonaline, piperettine, piperlongumine etc. is the officinal part of long pepper. Generally not much variations is observed on the crude alkaloid content of long pepper due to the variations in cultural inputs (Sheela, 1996). The result obtained in this experiment is also in conformity with the report of earlier workers. However, the variation obtained in total crude extract production per unit area are due to the difference in dry spike yield per unit area which are evident from Table 24 and Fig 18. The reasons attributed for higher dry spike yield per unit area under section 5.4 are applicable for higher crude extract production per unit area also.

5.7. PLANT NUTRIENT STATUS

Methods of irrigation significantly influenced boron and phosphorus status of plants and in both cases drip irrigation had a positive effect whereas N, K and Mg levels were unaffected by treatment effects. Application of water soluble NPK + PGPR Mix- I + Fluorescent pseudomonas + Mg + B significantly enhanced N and B concentration in plants where as liquid organic manures + PGPR Mix- I + Fluorescent pseudomonas + Mg + B improved Mg content (Table 27). Among the different treatment combinations including control, M_1F_6 significantly improved K and Mg content (3.52 % and 0.208 %) and the per cent

Plate 3. Treatments vs Controls

a. Treatment combinations inside the poly cum shade house

b. Control

c. Root production in the interaction plot

d. Root production in the control plot

e. Dry matter production in the interaction plot

f. Dry matetr production in the contol plot increase over control mean were 76 and 163. Nitrogen and boron concentrations ranged from 1.06 % to 2.36 % and 11.09 ppm to 33.34 ppm respectively and the treatment combination M_1F_5 and M_2F_5 recorded higher contents and the per cent increase over control mean were 101 and 74 per cent respectively (Table 27). P content was unaffected by treatment combination. The micro nutrient B and secondary nutrient Mg are essential for achieving higher growth and yield in long pepper. Studies conducted so far revealed a strong depression in root growth and development consequent to shortage of boron. Root elongation stops completely within two hours after transfer in to solution without boron (Chapman and Jackson, 1974). It is absolutely critical for reproduction, mitosis, pollen tube growth and pollen germination. It is also essential for calcium metabolism and utilization in crops. Boron requirement of crops is higher at reproductive stage than vegetative stage (Loomis and Durst, 1992). Magnesium is important for synthesis of chlorophyll molecule which imparts green colour to plants. It has other important functions in plant metabolism including protein synthesis, synthesis and activation of higher energy compounds and carbohydrate partitioning in plants. Mg is also involved in many enzymatic reactions, ribosomal integrity and structural stability of nucleic acids and membranes (Clarkson and Hanson, 1980). As the experiment was carried out in B and Mg deficient sandy soil, the required quantities of B and Mg were applied for uptake which is reflected in plant nutrient status (Table 27).

5.8. NUTRIENT UPTAKE

Positive and significant effect of methods of irrigation on nutrient uptake was observed and there was improvement in uptake in drip irrigation with respect to all the nutrients, *viz,* N, P, Mg and B except K. In general F_4, F_5 and F_6 enhanced the uptake of N, P, K, Mg and B. Among the treatment combinations including control the uptake of nutrients ranged from 16.52 kg ha^{-1} to 76.98 kg ha^{-1} for N, 1.14 kg ha^{-1} to 3.24 kg ha^{-1} for P, 28.34 kg ha^{-1} to 102.41 kg ha^{-1} for K, 0.97 kg ha^{-1} to 6.22 kg ha^{-1} for Mg and 24.23 g ha^{-1} to 105.70 g ha^{-1} for B (Table

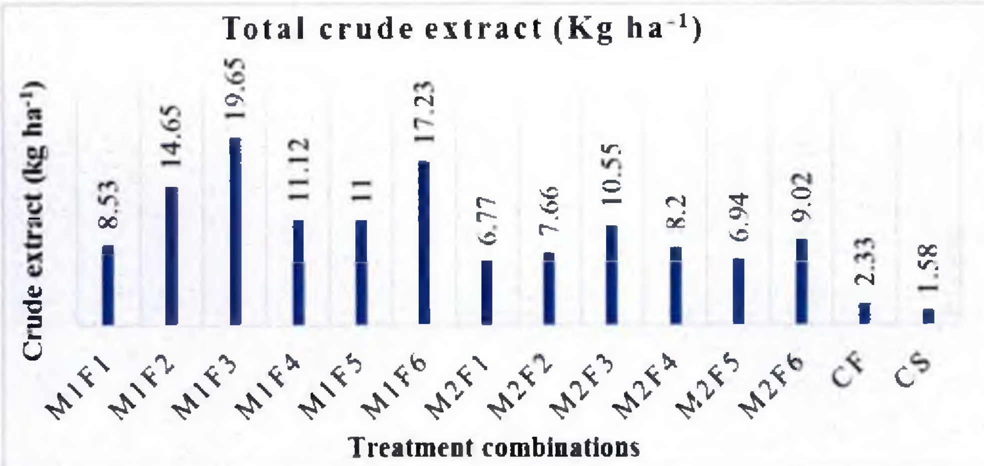


Fig 21. Total crude extract recovery as influenced by methods of irrigation and levels of fertigation

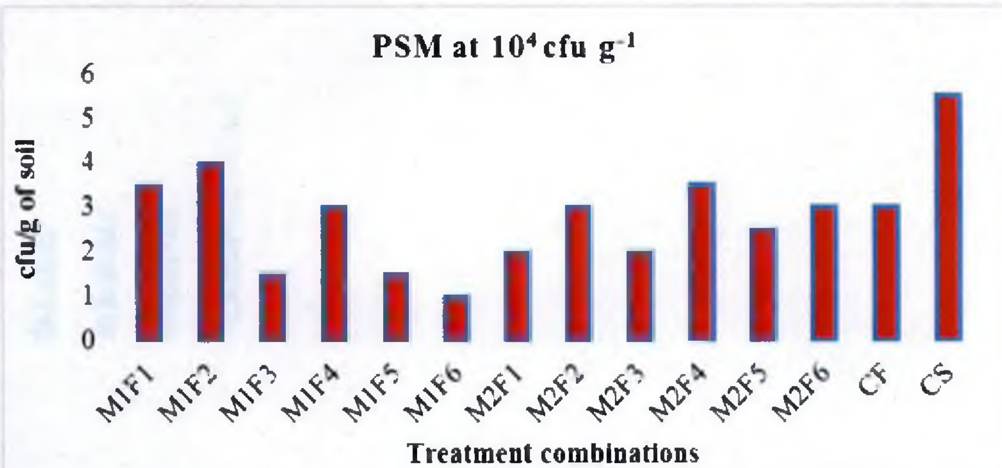


Fig 22. Number of phosphate solubilizing microorganisms (cfu per g of soil) as influenced by methods of irrigation and levels of fertigation

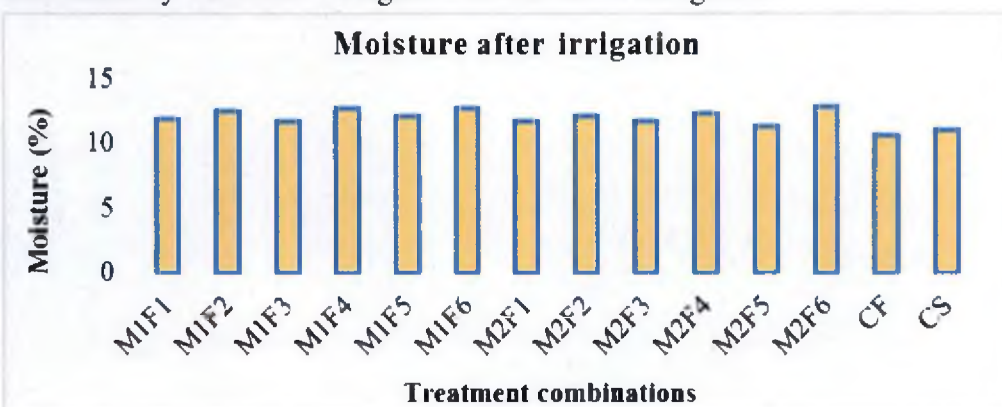


Fig 23. Moisture after irrigation (%) as influenced by methods of irrigation and levels of fertigation

28). M2F5 recorded higher values of Mg and B and the per cent increase over control mean were 397 and 240 respectively. M_1F_2, M_2F_4 and M_1F_4 were significant in uptake of N, P and K and the per cent increase over control mean were 308, 176 and 221 respectively (Table 28). Total uptake of nutrients is influenced by the total dry matter accumulation and the nutrient content. Wide variations in total dry matter production along with slight variation in nutrient concentration have resulted in differences in uptake of nutrients which is evident from Tables 25 and 27.

5.9. NUTRIENT STATUS OF SOIL AFTER THE EXPERIMENT

The status of certain nutrients alone were influenced by treatment effects. Methods of irrigation had no significance on N, P and Mg status of the soil after the experiment whereas drip irrigation significantly contributed to higher levels of K and B. Potassium and Boron contents ranged from 74.55 kg ha^{-1} to 84.77 kg ha^{-1} and 4.11 kg ha^{-1} to 4.45 kg ha^{-1} respectively (Table 29). Combined application of water soluble NPK + PGPR Mix- I + Fluorescent pseudomonas + Mg + B (F_5) significantly improved N, Mg and B content of the soil after the experiment which ranged from 286.23 kg ha^{-1} to 307.13 kg ha^{-1} , 47.51 kg ha^{-1} to 61.24 kg ha^{-1} and 2.29 kg ha^{-1} to 6.49 kg ha^{-1} respectively. Higher nitrogen levels were estimated in control plots which ranged from 278.44 kg ha^{-1} to 319.53 kg ha^{-1}. M_2F_6 was found to improve the K content after the experiment where M_2F_5 and M_1F_5 were found to increase Mg and B content.

The nutrient status of soil after the experiment was influenced by initial soil moisture status, uptake, generation and loss of nutrients associated with beneficial and harmful micro flora, environmental condition etc. Wide variation in plant nutrient uptake was observed with respect to all the nutrients studied. However a proportionate variation in soil nutrient status could not be observed with respect to all the nutrients which might be due to the supply of varying doses of nutrients through soluble fertilizer, liquid organic manure, Mg and B etc. Even though B and Mg were added through fertigation, its uptake was found to be less consequent to lower dry matter production compared to other treatments which might have resulted in its soil status (Table 28). Introduction of PGPR Mix- I and fluorescent pseudomonas into the system might have resulted in fixation and mineralization of certain nutrients which might have led to differences in soil nutrient status.

5.10. PHOSPHATE SOLUBILIZING MICROORGANISMS.

Positive and significant influence of fertigation on number of phosphate solubilizing microorganisms was observed at 10^4 dilution of soil solution (Table 30 and Fig 22). Rotational application of vermiwash, cow urine and fermented plant juice had significant and positive effect in increasing phosphate solubilizing microorganisms in the soil. Phosphate solubilizing microorganism include an array of bacteria *viz, Pseudomonas, Azospirillum, Bacillus, Rhizobium, Arthrobacter and Flvobacterium* and fungi *Aspergillus* and *Penicillium* (Rodriguez and Fraga, 1999). Liquid organic manures dispersed through fertigation contain substantial population of all the above categories of microorganisms (Gore and Srinivasa, 2011). Though not significant population of these microorganism was higher in drip irrigation probably due to favourable oxygen- nutrient water balance existed in the rhizosphere. The reasons attributed for the existence of favourable rhizosphere are furnished in section 5.1 and 5.2.

5.11. SOIL MOISTURE

Methods of irrigation, levels of fertigation and the integration of these two factors had no significant influence on moisture content of the soil after and before irrigation. However among the treatments including control, M_2F_6 and M_1F_3 retained higher moisture levels after and before irrigation respectively. The moisture content of soil before and after irrigation ranged from 7.34 % to 8.97 % and 10.65% to 12.89 % respectively. After irritation M_2F_6 recorded 12.89 % moisture which was 19 per cent higher compared to control mean. A moisture content of 8.97 % which was 19.6 per cent higher compared to control mean was

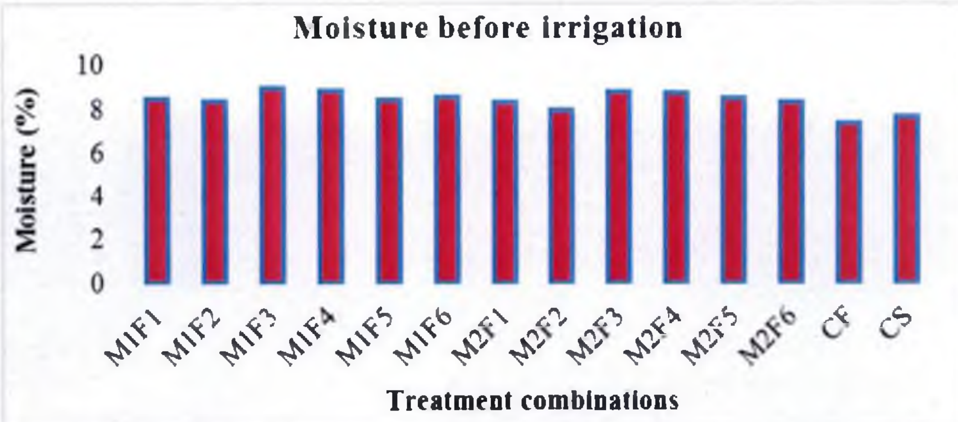


Fig 24. Moisture before (%) irrigation as influenced by methods of irrigation and levels of fertigation

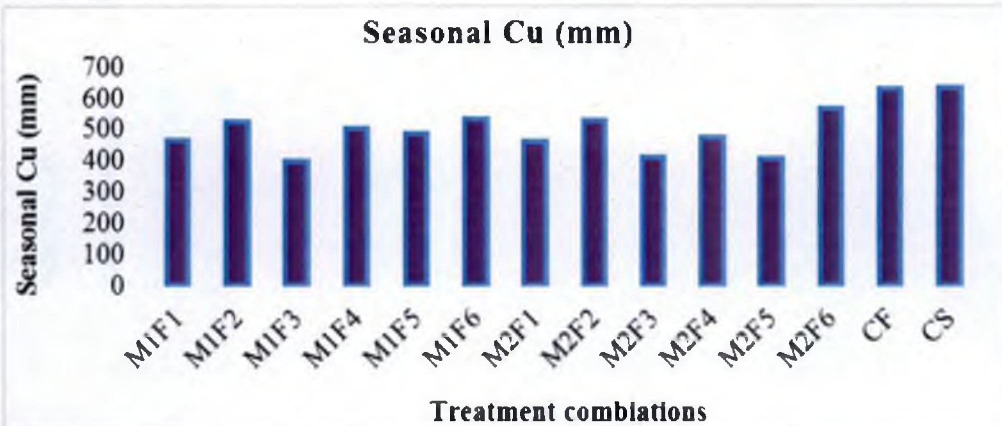


Fig 25. Seasonal consumptive use as influenced by methods of irrigation and levels of fertigation

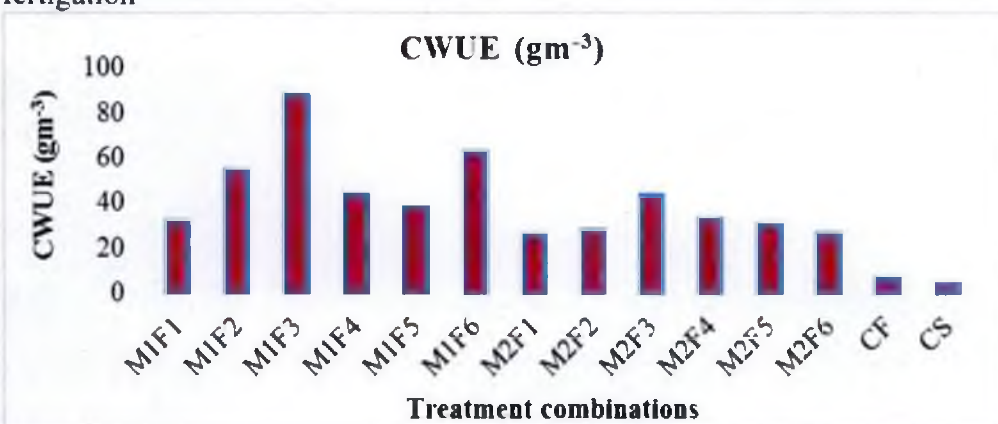


Fig 26. Crop water use efficiency as influenced by methods of irrigation and levels of fertigation

recorded by treatment combination M_1F_3 before irrigation. Application of liquid organic manures through drip irrigation facilitates soil to enhance its water holding capacity and enabled to hold more amount of moisture after irrigation probably due to favourable effect of liquid organic manure as explained in section 5.5. Combined application PGPR Mix- I and Fluorescent pseudomonas is instrumental in improving physical properties of soil (Mazinani *et al.*, 2012). Application of water soluble NPK through microsprinkler enable the soil to retain more moisture in the root zone before next irrigation probably because of enhanced horizontal moisture flow compared to vertical movement which might have reduced the plant uptake of water as moisture was away from root zone.

Seasonal consumptive use, mean daily consumptive use and crop coefficient ranged from 398.54 mm to 632.65 mm, 1.44 mm to 2.30 mm and 0.51 to 0.81 respectively (Table 31 and Fig 25). Methods of irrigation, levels of fertigation and different treatment combination had no effect in influencing above parameters. However the effect of treatment combination including control was conspicuous in influencing all the above parameters and soil application followed by foliar spray of nutrients in the control plot registered higher values. Seasonal consumptive use, mean daily consumptive use and crop coefficient depend mainly on crop evapotranspiration. Data recorded by steady state porometer revealed the higher evaporative demand of atmosphere outside the poly cum shade house that is in the two control plots (Table 18). All the major microclimatic parameters, i.e., total solar radiation, PAR and temperature were higher outside the poly cum shade house where the control treatments were raised. Seasonal consumptive use, mean daily consumptive use and crop coefficient showed higher values. This is also evident from transpiration data recorded from control plots using steady state porometer.

The treatments have spectacular effects on water use efficiency. Crop water use efficiency and field water use efficiency ranged from 4.71 gm^{-3} to 88.29 gm^{-3} and 3.06 gm^{-3} to 36.32 gm^{-3} respectively. Microsprinkler irrigation, application of water soluble NPK + PGPR Mix- I + Fluorescent pseudomonas

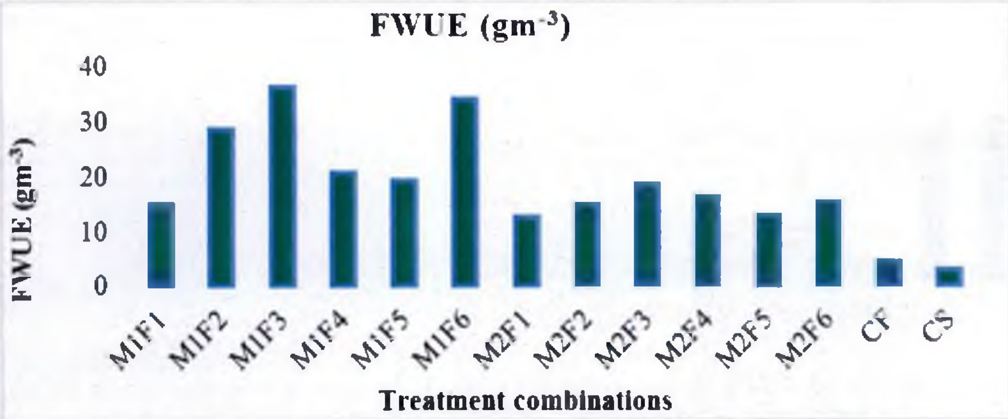


Fig 27. Field water use efficiency as influenced by methods of irrigation and levels of fertigation

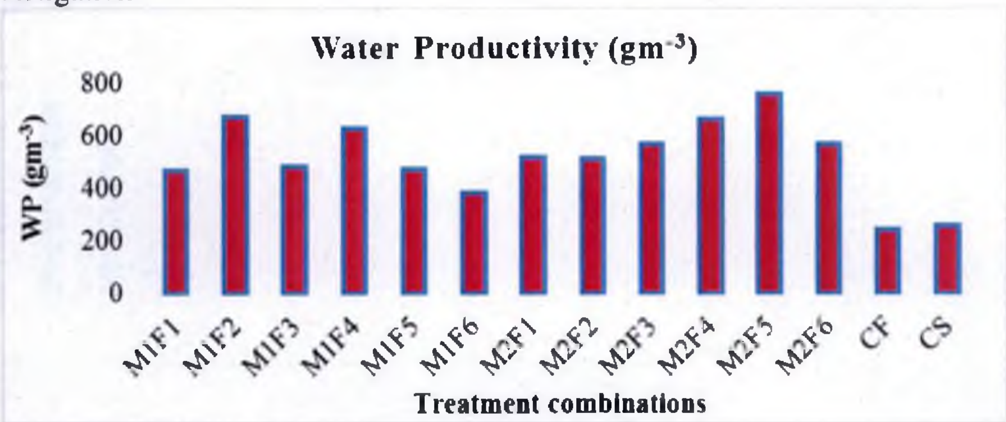


Fig 28. Water productivity as influenced by methods of irrigation and levels of fertigation

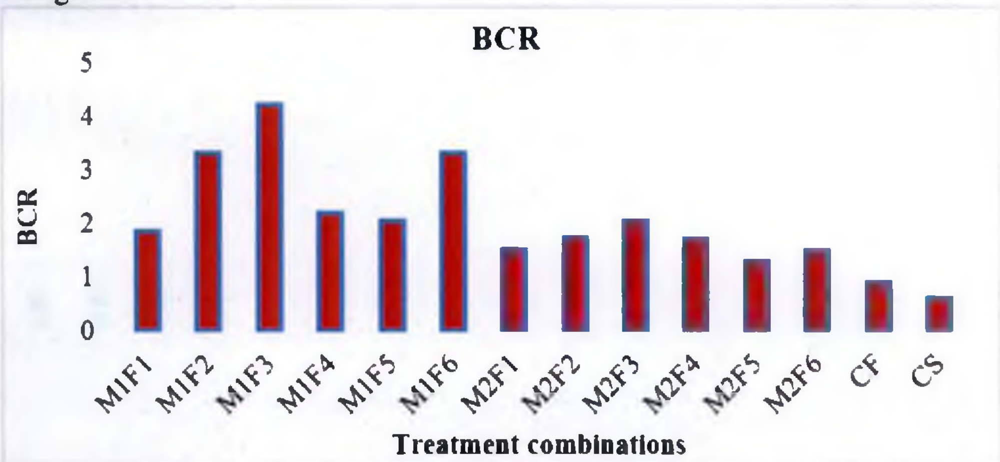


Fig 29. Benefit cost ratio as influenced by methods of irrigation and levels of fertigation

positively and significantly improved crop and field water use efficiencies (Table 31 and Fig 26 and 27). The main and interaction effects which registered higher dry spike yield also recorded higher crop and field water use efficiencies. Evapotranspiration and water requirements were lower in poly cum shade house compared to control plots. This has resulted in higher crop and field water use efficiencies in M_1F_3. The reasons attributed for higher spike production under section 5.4 is also applicable for higher crop and field water use efficiencies.

Water proauctivity of long pepper ranged from 243.34 gm^{-3} to 758.85 gm^{-3}. Drip irrigation enhanced water productivity to the tune of 139 per cent compared to control mean (Table 31). Among the treatments including control application of water soluble NPK + PGPR Mix- I + Fluorescent pseudomonas + Mg + B through drip irrigation was found to enhance water productivity by 203 per cent over control mean (Table 31and Fig 28). Water productivity is mainly influenced by two factors that is total dry matter production and the total water depleted. The treatment combination with higher dry matter production coupled with lower water depletion resulted in highest water productivity. The reasons ascribed for lower water requirement in 5.3 and 5.11 are also applicable here. Frequent irrigation through drippers will result in reduced soil moisture fluctuations in the effective root zone of plants thereby ensuring proper moisture for metabolic activities. This might be a reason for the increased water productivity in drip irrigation

5.12. ECONOMIC ANALYSIS

Economic analysis proved the significance of microsprinkler, water soluble NPK + PGPR Mix- I + Fluorescent pseudomonas and their combination in achieving higher gross return, net returns and BCR. Gross returns ranged from Rs. 0.29 lakh to Rs 3.5 lakh per ha and the highest gross return was associated with the treatment combination M_1F_3 followed by M_1F_6. Net returns ranged from Rs -0.04 lakh to Rs 2.68 lakh (Table 32 and Fig 29). Net returns and BCR followed a similar trend as that of gross returns. The treatment combination M_1F_3

recorded the highest dry spike yield. The trend was similar with respect to all the economic parameter studied. Increasing the productivity of long pepper planted in poly cum shade house erected in the interspaces of coconut garden by application of water soluble NPK + PGPR Mix- I + Fluorescent pseudomonas through microsprinkler irrigation is beneficial for improving gross return, net return and BCR.

SUMMARY

6. SUMMARY

The experiment entitled 'source efficacy of nutrients and fertigation in long pepper (*Piper longum* L.)' was carried out in the Instructional farm attached to the College of Agriculture, Padannakkad during 2014 to 2016 to study the effect of micro irrigation and fertigation with water soluble fertilizers, liquid organic manures and plant growth promoting rhizobacteria on the growth, productivity, quality and economics of intercropped long pepper under poly cum shade house in coconut garden.

Methods of irrigation significantly influenced the vine length at all stages of growth and drip irrigation resulted in highest vine length of 109.70 cm. Fertigation with water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas + Mg + B was found to be favourable for enhancing vine length. At 15 MAP the greatest vine length of 150.95 cm was registered by treatment combination M_2F_5 which was significantly different from all other treatment combinations.

Methods of irrigation significantly influenced leaf number and at 15 MAP, there was 11.76 per cent increase in leaf number with drip irrigation compared to micro sprinkler. Fertigation with water soluble NPK+ PGPR Mix– I + Fluorescent pseudomonas significantly and positively increased leaf number at all stages of growth except at 7 MAP. The treatment combination M_2F_1, significantly increased leaf number at 7, 11, 13 and 15 MAP. Among controls, positive and significant improvement in leaf number was observed at 7 MAP due to soil application of nutrients.

Drip irrigation significantly improved leaf area index at 7, 9, and 13 MAP. However significant influence of microsprinkler was observed at 11 and 15 MAP. The effect of levels of fertigation on leaf area index was significant and F_3 on par with F_2, F_6, F_5, F_5, and F_2 registered higher LAI at 7, 9, 11, 13 and 15 MAP respectively. Significance of interaction effects on LAI was evident at all stages of growth.

Drip irrigation was found effective in improving the number of branches at all stages of growth. Fertigation with water soluble NPK fertilizer gave higher number of branches throughout the period of experimentation. Interaction effects didn't significantly influence number of branches at any of the growth stages of long pepper.

Microsprinkler was found to be beneficial in significantly improving root number at 11 and 13 MAP. The effect of levels of fertigation on root number was significant at all growth stages. Interaction effects also recorded the significance of treatment combinations in increasing root number throughout the period of experimentation.

Methods of irrigation influenced root length only at 7 MAP and drip irrigation was found beneficial. Levels of fertigation and interaction effects didn't significantly influence root length at any stages of growth.

Methods of irrigation significantly influenced root weight only at two stages of growth, i.e., at 9 and 11 MAP and at both stages drip irrigation was found advantageous. Levels of fertigation and interaction effects significantly influenced root weight only at 9 MAP. The treatment combination M_2F_4 which was on par with M_2F_3 registered the highest root weight of 17.40 g.

At 7 and 9 MAP, root spread was found to be significantly influenced by drip irrigation. Levels of fertigation were found to be significantly influence root spread only at 7 and 13 MAP. The significant effect of interactions between methods of irrigation and levels of fertigation was observed only at 7 MAP.

Methods of irrigation, levels of fertigation and their interaction effects had no significant influence on relative leaf water content recorded at any of the stages of growth of long pepper. Between two controls, significant difference with respect to RLWC was observed only at 13 MAP.

Methods of irrigation didn't significantly influence the stomatal conductance at any of the growth stages except at 9 MAP. Levels of fertigation and interaction effects didn't significantly influence stomatal conductance at any of the growth stages.

SPAD meter readings were not at all influenced by methods of irrigation, levels of fertigation and their interaction effects. But between treatments including control, significant difference was observed. At 7, 9, 11, 13 and 15 MAP, all the twelve treatment combinations were on par and significantly different from the two control treatments with respect to the SPAD meter reading.

Methods of irrigation significantly influenced leaf temperature only at 13 MAP. Levels of fertigation and interaction effects had no significant effect on leaf temperature at any of the growth stages.

Data on total solar radiation and PAR measured in the poly cum shade house erected in the interspaces of coconut garden and in the open interspaces indicate higher values of both the microclimate parameters in the open interspaces of coconut garden compared to poly cum shade house.

Microsprinkler method of irrigation recorded the highest number of spikes of 43.41. At all stages of growth, considerable improvement in spike number was evident due to the effect of levels of fertigation and F_3 recorded the highest spike number. The treatment combination M_1F_3 recorded the highest total number of spikes per plant which was significantly different from all other treatment combinations. No significant difference was observed between the two control treatments in influencing spike number.

Microsprinkler irrigation recorded significantly higher total fresh spike yield per plant. Among the levels of fertigation, F_3 on par with F_6 significantly contributed to total spike yield per plant. The treatment combination, M_1F_3 on par with M_1F_6 registered the highest total fresh spike yield of 37.68 g per plant.

Similar to the fresh spike yield per plant, microsprinkler irrigation significantly contributed to dry spike yield per plant. F_3 on par with F_6 registered total dry spike yield of 4.25 g per plant. The remarkable contribution of the treatment combination M_1F_3 was evident on total dry spike yield per plant as well.

Methods of irrigation significantly increased dry matter production at all stages and remarkable effect of drip irrigation was evident throughout the stages of experimentation. Levels of fertigation significantly influenced dry matter production at all harvests except at 9 MAP and the trend was not uniform. Remarkable increase in dry matter production was observed due to interaction effects only at 7 and 15MAP. At 7 MAP, M_2F_4 on par with M_2F_3, M_1F_5, M_1F_6, M_2F_1 and M_1F_4; and at 15 MAP, M_1F_2 on par with M_2F_6, M_2F_4 and M_2F_5 gave higher dry matter production per plant. The two control treatments had no significant effect on dry matter production per plant.

Methods of irrigation didn't significantly influence the crude extract content. However levels of fertigation remarkably influenced the crude extract per cent and F_3 on par with F_5, F_1 and F_6 recorded significantly higher values. Interaction effects also influenced crude extract per cent. Similar to the total dry spike production per hectare, total crude extract production per hectare was also found to be significantly contributed by microsprinkler method of irrigation. Levels of fertigation enhanced total crude extract production per hectare and F_3 resulted in the highest value which was on par with F_6. Total crude extract production was found to be significantly influenced by interaction effects and the treatment combination M_1F_3 on par with M_1F_6 registered higher values.

Methods of irrigation significantly influenced phosphorous and boron contents only and in both cases drip irrigation found to be beneficial. Levels of fertigation significantly influenced nitrogen, magnesium and boron concentrations. Nitrogen and phosphorous contents alone were significantly influenced by the interaction effects.

Method of irrigation increased the uptake of all nutrients except K. Levels of fertigation also improved the uptake of all the nutrients except P. Among the different treatment combinations M_1F_2 on par with M_2F_4, M_2F_6 and M_2F_5; and M_2F_5 on par with M_2F_6, M_1F_2, M_2F_4 and M_1F_4 significantly improved the uptake of N and Mg, respectively.

Potassium and boron status of soil alone were found to be significantly influenced by methods of irrigation and in both cases, drip irrigation registered higher status compared to microsprinkler method of irrigation. Levels of fertigation showed its significance on N, Mg and B concentrations and F_5 in all the three cases registered higher values. Mg and B concentrations of soil alone were found to be significantly influenced by the interaction effects of different treatment combinations.

The population of phosphate solubilizing microorganisms were not at all influenced by the methods of irrigation. Levels of fertigation significantly influenced the population of phosphate solubilizing microorganisms only at 10^4 dilution. Interaction effects of treatment combinations didn't significantly influence the population of microorganisms at any of the dilutions tried.

The main effects and interaction effects of different treatment combinations had no significant influence on soil moisture content, moisture before and after irrigation, seasonal consumptive use and mean daily consumptive use. Crop water use efficiency and field water use efficiency were found to be significantly influenced by the interaction effects of different treatment combinations including control. Between the methods of irrigation microsprinkler recorded significantly higher CWUE. The trend was also similar with respect to FWUE as well. Levels of fertigation also remarkably influenced the CWUE and F_3 recorded the highest CWUE. A similar trend was observed in the case of

FWUE as well. Among the interaction effects, M_1F_3 recorded the highest CWUE which was significantly different from all other treatment combinations. The same treatment combination recorded the highest FWUE which was on par with M_1F_6. Control treatments neither significantly influenced CWUE nor FWUE. Water productivity was also found to be significantly influenced by methods of irrigation and drip irrigation recorded the highest water productivity. Levels of fertigation and interaction effects of different treatment combinations didn't significantly influence water productivity.

Microsprinkler method of irrigation recorded significantly higher gross returns, net returns and BCR. Among the levels of fertigation, F_3 recorded significantly higher gross returns, net returns and BCR. Interaction effects also indicated significant improvement of gross returns, net returns and BCR on integration of microsprinkler and water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas.

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ABSTRACT

SOURCE EFFICACY OF NUTRIENTS AND FERTIGATION IN

LONG PEPPER (*Piper longum* L.)

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Abstract of the Thesis

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ABSTRACT

Long pepper (*Piper longum* L.) is an economically important medicinal crop widely recommended for commercial mediculture among the progressive farmers of the state. 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.

The experiment entitled 'Source efficacy of nutrients and fertigation in long pepper (*Piper longum* L.)' was carried out with the objective to study the effect of micro irrigation and fertigation with water soluble fertilizers, liquid organic manures and plant growth promoting rhizobacteria on the growth, productivity, quality and economics of intercropped long pepper under poly cum shade house in coconut garden.

The trial carried out in factorial RBD with two replication for a period of two years consisted of combinations of two methods of irrigation *viz,* M_1: microsprinkler and M_2: drip and six levels of fertigation *viz,* F_1: Water soluble NPK fertilizer, F_2: Liquid organic manures, F_3: Water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas, F_4: Liquid organic manures + PGPR Mix – I + Fluorescent pseudomonas, F_5: Water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas + Mg + B, and F_6: Liquid organic manures + PGPR Mix– I + Fluorescent pseudomonas + Mg + B; besides two control treatments namely CF: Intercropping in coconut garden (foliar application) and CS: Intercropping in coconut garden (soil application).

Methods of irrigation significantly influenced the vine length at all stages of growth and drip irrigation recorded the highest values throughout the period of experimentation. Significant influence of different treatment combinations including control was evident in leaf number at all stages of growth and in general

M_2F_1 recorded the highest leaf number. Interaction effects didn't significantly influence number of branches at any of the growth stages of long pepper.

Microsprinkler irrigation recorded the highest total number of spikes (43.41/plant) which was 71.90 per cent higher compared to drip irrigation. Except at 7 MAP, interaction effects significantly improved spike number and total number of spikes. Spectacular improvement in fresh spike yield per plant at various growth stages and total fresh spike yield per plant was evident with microsprinkler irrigation. Levels of fertigation also significantly influenced both fresh spike yield per plant and total fresh spike yield per plant. Interaction effects also indicated its significance on fresh spike yield per plant at all stages of growth except 7 MAP. The treatment combinations, M_1F_3 at 9 MAP, M_1F_3 on par with M_1F_6, M_1F_5 and M_1F_2 at 11 MAP, M_1F_3 on par with M_1F_6 and M_1F_2 at 13 MAP; and M_1F_3 on par with M_1F_6 at 15 MAP gave higher fresh spike yield per plant. Similar to total fresh spike yield per plant and fresh spike yield per plant at various harvests, total fresh spike yield per hectare and dry spike yield per hectare at various harvests were found to be significantly influenced by the main and interaction effects of treatments including control.

Between the two methods of irrigation, microsprinkler recorded significantly higher CWUE which was 69.50 per cent higher over drip system. The trend was also similar with respect to FWUE as well. Levels of fertigation also remarkably influenced the CWUE and F_3 recorded the highest CWUE of 65.97 g m^{-3}. A similar trend was observed in case of FWUE also. Among the interaction effects M_1F_3 recorded the highest CWUE which was significantly different from all other treatment combinations. The same treatment combination recorded the highest FWUE of 36.32 g m^{-3} (M_1F_3) which was on par with M_1F_6. Water productivity was also found to be significantly influenced by methods of irrigation. It is concluded that foliar application water soluble NPK fertilizer + PGPR Mix– I + Fluorescent pseudomonas through microsprinkler irrigation is found beneficial for significant improvement of yield, productivity and profitability.

സംഗ്രഹം

കേരളത്തിലെ കാലാവസ്ഥക്ക് വളരെ അനുയോജ്യമായ ഒരു ഔഷധസസ്യ മാണ് തിപ്പലി. ഔഷധമൂല്യം വളരെയധികമുള്ള തിപ്പലി വിവിധതരം ആയുർവേദ മരുന്നുകളുടേയും ഔഷധകൂട്ടുകളുടേയും ഉത്പാദനത്തിനായി ഉപയോഗിച്ചു വരുന്നു. എന്നാൽ നിലവിലുള്ള ഉത്പാദനം വളരെ പരിമിതവും പരിപോഷിപ്പിക്കപ്പെടേണ്ടതുമാണ്. കൃത്യതാ കൃഷിക്ക് അനുയോജിച്ച വിള എന്നതിലുപരി തണൽ ഇഷ്ടപ്പെടുന്ന ഒരു വിള കൂടിയാണ് തിപ്പലി. അതിനാൽ തെങ്ങുകൾക്കിടയിൽ ഒരു മിശ്രവിളയായി കൃഷി ചെയ്യാൻ സാധിക്കും. നിലവിലുള്ള കൃഷി പരിപാലനമുറകൾ തിപ്പലിയിലെ ഉത്പാദനം വർദ്ധിപ്പിക്കാൻ തക്കവണ്ണം പര്യാപ്തമല്ല.

ഈ സാഹചര്യത്തിൽ തളിനന, തുള്ളിനന, ലയന സ്വഭാവമുള്ള രാസവളങ്ങൾ, ദ്രാവകരൂപത്തിലുള്ള ജൈവവളങ്ങൾ, പി.ജി.പി.ആർ. മിക്സ് 1, ഫ്ളൂറസെൻ്റ് സ്യുഡോമോണാസ് എന്നിവ അടങ്ങിയ വളസേചനം അവലംബിച്ചുകൊണ്ട് തെങ്ങു കൾക്കിടയിൽ തണൽ പായ പതിച്ച മഴമറയിൽ തിപ്പലിയുടെ ഉത്പാദനക്ഷമത വർദ്ധിപ്പിക്കാനും കൃഷി ലാഭകരമാക്കാനുമുള്ള ഒരു പരീക്ഷണം നടത്തുകയുണ്ടായി.

ഫാക്ടോറിയൽ ആർ ബി ഡി യിൽ നടത്തിയ പരീക്ഷണത്തിൽ ജലസേചന സംവിധാനങ്ങളുടെയും വളസേചനത്തിന്റെയും സംയോജനമാണ് പരീക്ഷിക്കപ്പെട്ടത്. തളിനന, തുള്ളിനന എന്നീ രണ്ടു തരത്തിലുള്ള ജലസേചന സംവിധാനങ്ങൾ നൽകിയിട്ടുണ്ടായിരുന്നു. ആറു തരത്തിലുള്ള വളസേചനം ഏർപ്പെടുത്തിയിട്ടുണ്ടായിരുന്നു. അവ ക്രമേണ ലയനസ്വഭാവമുള്ള എൻ പി കെ വളങ്ങൾ, ദ്രാവകരൂപത്തിലുള്ള ജൈവ വളങ്ങൾ, ലയനസ്വഭാവമുള്ള എൻ പി കെ വളങ്ങൾ + പി.ജി.പി. ആർ. മിക്സ് 1 + ഫ്ളൂറസെൻ്റ് സ്യുഡോമോണാസ്, ദ്രാവകരൂപത്തിലുള്ള ജൈവവളങ്ങൾ + പി.ജി. പി.ആർ. മിക്സ് 1 + ഫ്ളൂറസെൻ്റ് സ്യുഡോമോണാസ്, ലയനസ്വഭാവമുള്ള എൻ പി കെ വളങ്ങൾ + പി.ജി.പി. ആർ. മിക്സ് 1 + ഫ്ളൂറസെൻ്റ് സ്യുഡോമോണാ സ് + മഗ്നീഷ്യം + ബോറോൺ, ദ്രാവകരൂപത്തിലുള്ള ജൈവവളങ്ങൾ + പി.ജി.പി. ആർ.

മിക്സ് 1 + ഫ്ളൂറസെന്റ് സ്യൂഡോമോണാസ് + മഗ്നീഷ്യം + ബോറോൺ എന്നിവയായിരുന്നു. ഇവയുടെ സ്വീകാര്യത താരതമ്യം ചെയ്യുവാനായി നിർദ്ധിഷ്ട വിളപരിപാലനം (KAU) ഇലയിലും ചുവട്ടിലും നൽകിയവയും നിലനിർത്തിയിരുന്നു.

തുള്ളിനന ചെടികളുടെ നീളം വർദ്ധിപ്പിക്കാൻ സഹായകരമാണെന്ന് കണ്ടെത്തുകയുണ്ടായി. കൂടുതൽ ഇലകളുടെ ലഭ്യതക്കായി ലയനസ്വഭാവമുള്ള എൻ പി കെ വളങ്ങൾ തുള്ളിനന വഴി നൽകുകയാണ് അഭികാമ്യം. തളിനന തിരികളുടെ എണ്ണം വർദ്ധിപ്പിക്കുവാൻ സഹായകരമാണ്. നട്ട് ഏഴ് മാസത്തിനുശേഷം തളിനന, തുള്ളിനന, വളസേചനം എന്നിവയുടെ സംയോജനം വഴിയും തിരികളുടെ എണ്ണം വർദ്ധിപ്പിക്കാം. വിളവ് കൂട്ടുന്നതിനായി തളിനന വഴി ലയന സ്വഭാവമുള്ള എൻ പി കെ വളങ്ങൾ + പി.ജി.പി.ആർ. മിക്സ് 1 + ഫ്ളൂറസെന്റ് സ്യൂഡോമോണാസ് നൽകുന്നതാണ് ഗുണകരം. മേൽപറഞ്ഞ സംയോജനം വഴി ഹെക്ടറിൽ നിന്ന് 2355 കിലോ ഗ്രാം പച്ച തിപ്പലി (ഉണക്ക് – 350 കിലോ ഗ്രാം) ലഭിക്കുന്നതാണ്.

തളിനന വഴി തിപ്പലിയിൽ ജലത്തിന്റെ ഉപയോഗക്ഷമത (CWUE) 69 ശതമാന ത്തോളം വർദ്ധിപ്പിക്കാൻ സാധിക്കുന്നതാണ്. തുള്ളിനന അവലംബിക്കുക വഴി ജലവിനിയോഗം പരമാവധി കുറക്കുവാൻ സാധിക്കുന്നതാണ്. നിലവിൽ തിപ്പലിയിലുള്ള വിള പരിപാലന മുറകളെ അപേക്ഷിച്ച് തളിനന, തുള്ളിനന എന്നീ ജലസേചന സംവിധാനങ്ങളും വളസേചനവും നൽകുന്നതാണ് വിളവ് കൂട്ടുന്നതിന് ഉത്തമം.

തളിനന, ലയനസ്വഭാവമുള്ള എൻ പി കെ വളങ്ങൾ + പി.ജി.പി. ആർ. മിക്സ് 1 + ഫ്ളൂറസെന്റ് സ്യൂഡോമോണാസ് എന്നിവയുടെ സംയോജനം തിപ്പലിയിൽ വിളവ് വർദ്ധിപ്പിക്കുവാനും അതുവഴി കൃഷി ലാഭകരമാക്കുവാനും സഹായിക്കുന്നതാണ്.

APPENDIX

Appendix 1

Monthly weather data during the crop period

Period	Maximum temperature (^0C)	Minimum temperature (^0C)	Rainfall (mm)	Relative humidity (%)	Evaporation (mm)
January 2015	31.66	19.34	0.00	73.79	3.34
February 2015	32.56	19.98	0.00	74.77	3.95
March 2015	32.58	23.51	0.00	75.19	4.58
April 2015	33.03	23.98	58.00	74.08	4.45
May 2015	32.62	23.94	126.10	78.03	3.29
June 2015	30.76	22.75	532.60	85.03	1.97
July 2015	29.96	23.42	902.00	88.08	2.43
August 2015	30.35	23.41	17.62	87.24	2.94
September 2015	31.21	23.44	12.51	87.91	3.48
October 2015	31.35	23.62	265.70	84.57	3.15
November 2015	31.39	23.05	106.80	81.75	2.95
December 2015	32.26	21.73	1.60	81.20	3.22
January 2016	32.25	19.57	0.00	75.00	3.67
February 2016	32.25	21.94	0.00	75.58	4.53
March 2016	33.61	24.57	0.00	74.78	5.34