MULTIPLE CROPPING AND MICROSITE ENRICHMENT IN VETIVER (*Chrysopogon zizanioides* (L.) Nash

by

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "**Multiple cropping and microsite enrichment in vetiver (*Chrysopogon zizanioides* (L.) Nash**" is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other university or society.

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LIST OF ABBREVIATIONS

%	-	Per cent
^0C	-	Degree Celsius
AMF	-	Arbuscular Mycorrhizal Fungi
BCR	-	Benefit:cost ratio
CD	-	Critical difference
cm	-	Centimetre
cm^2	-	Square centimetre
cm^3	-	Cubic centimetre
CPE	-	*Cumulative pan evaporation*
Cu	-	Consumptive use
et al	-	And others
FC	-	Field capacity
Fig.	-	Figure
g cc^{-1}	-	Gram per cubiccentimetre
g $plant^{-1}$	-	Gram per plant
g	-	Gram
ha^{-1}	-	Per hectare
K_c	-	Crop coefficient
kg m^{-3}	-	Kilogram per cubic metre
kg	-	Kilogram
l	-	Litre
m	-	Metre
m^2	-	Square metre
m^3	-	Cubic metre
MAP	-	Months after planting
mg g^{-1}	-	Milli gram per gram
ml	-	Millilitre
mm	-	Millimetre
MSL	-	Mean sea level
N	-	Nitrogen
NS	-	Not significant
PWP	-	Permanent wilting point
RGP	-	Root growth potential
RLWC	-	Relative leaf water content
Rs.	-	Rupees
SGP	-	Sapling growth potential
SQ	-	Sturdiness quotient
t ha^{-1}	-	Tonnes per hectare

Introduction

1. INTRODUCTION

Vetiver (*Chrysopogon zizanioides*) is the only grass cultivated specifically for its root extracted essential oil which is a complex mixture of sesquiterpene alcohols and hydrocarbons. The oil is extensively used in perfumes and cosmetics. The World Bank has promoted the Vetiver System for various applications since the 1980s (Truong and Baker, 1998). Besides, vetiver roots are widely used for medicinal purposes and are used for the treatments of diseases like cold, cancer etc. The roots are also used to make handicrafts and to produce ethanol. Due to its widely soothening effects vetiver oil is used in aroma therapy also.

Fast growing deep penetrating roots and high biomass production potential of vetiver grass has opened newer opportunities for its utilization in mitigating global warming through photosynthetic capture of atmospheric carbon and its sequestration in subsoil horizons. Penetrating deep root system of vetiver would facilitate long-term locking of atmospheric carbon below plough layer with reduced chances of being recycled to atmosphere and recuperate soil carbon sink (Lavania and Lavania, 2009). Also, the technical advances in cellulosic conversion of plant biomass into fuel could offer integrated approach for optimum utilization of vetiver plantations thereby reducing the load from anthropogenic emissions. Vetiver could mitigate the collateral adverse effects of climate change, such as flood disaster, soil degradation, loss of water quality and quantity and land and water pollution through contamination and sedimentation.

In several parts of the world sustainability of traditional agricultural systems is threatened by degradation of crop lands due to complete removal of crop residues at harvest. Annual variations in the productivity of crops are commonly linked to periodic droughts and insufficient rainfall, periodical water logging and high runoff rates during the growing season. These problems leading to relatively low yields are associated with imbalance in soil hydrology. The only freshwater input is rainfall which is lost too much as blue water, *ie*, as direct run off and consequently, less water is available for crops, *ie*, as green water (Rockstrom, 1997). This imbalanced soil hydrology leads to physical deterioration of soil quality and absence of effective *in situ* soil and water conservation measures adversely affecting crop land itself. *In situ* rain water harvest and conservation practices help to increase the effective rainfall contribution for crop use besides extending moisture availability periods facilitating widening of irrigation intervals. Vetiver can be grown entirely on stored moisture if appropriate agro techniques are developed and integrated with suitable planting methods.

In situ composting in trenches and stubble mulching can be practised for early crop establishment in marginal lands which are poor in fertility and water holding capacity. This practice leads to rhizosphere modulation through organic matter addition and accelerated growth of vetiver. Besides this, the modification of land configuration by taking broad beds and trenches leads to the formation of minute microscopic micro water sheds that helps to harness and conserve rain water for further growth of vetiver. Surface mulching with occasional leaf prunings from standing vetiver crops extends moisture availability periods, by reducing soil evaporation.

Multiple cropping is one of the methods for multiple use of the same resource in vetiver gardens generating higher biomass. Ideal crop geometry and modification of canopy architecture facilitate crop intensification in both spatial and temporal dimensions. In this context, experiments were carried out to study the effect of single, dual and combined application of microbial inoculants on quality planting material production and also to develop eco-friendly techniques to achieve higher root and oil productivity in vetiver with special reference to climate change mitigation.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The investigation entitled 'Multiple cropping and microsite enrichment in vetiver (*Chrysopogon zizanioides* (L.) Nash' was undertaken to develop agro techniques for quality planting material production and enhancing root and oil yield in vetiver. The nursery trial was conducted to study the effect of single, dual and combined application of microbial inoculants on quality planting material production. A field experiment was also conducted to standardize methods for higher root and oil production in vetiver with special reference to climate change mitigation. The literatures pertaining to the subject with special emphasis on vetiver are reviewed hereunder. Wherever sufficient literature on vetiver are not available, studies on related crops and cropping situations are also reviewed.

2.1 Vetiver- Ecological and economic significance

The extensive fibrous root system of vetiver penetrates into the soil at great depths and breaks through hardpan as thick as even 15 cm. They were also found to have 'innate' power to penetrate a fairly thick layer of asphatic concrete. On slopes underlain with weathered rock, boulders or relatively hard layer, its penetrating roots will provide anchorage by root tendron action. This action is comparable to a nail which could penetrate deep layers of soils whose texture may be quite hard, and at the same time it has the ability to hold soil particles together through its extensive fibrous roots., thus avoiding soil erosion due to wind and water, making it well appreciated by road engineers as the 'living nail'.

Yoon (1991) obtained shoot: root ratios of 1.0:0.3 to 1.0:0.4 for vetiver grown on a range of soil types. The sand culture of vetiver showed shoot: root ratios of 1:1.05 to 1:1.15 (Mckenzie, 2002). Vetiver roots are commonly reported to reach 2 m depth. Greenfield (2002) reported a root depth of 3.6 m after 8 months of growth. The benchmark experiments on vetiver root strength in 1996 were an important step towards its wider acceptance. The experiments confirmed a mean tensile strength of some 75 MPa at 0.7-0.8 mm root diameter (Hengchaovanich and Nilaweera, 1996). The roots of vetiver grow rapidly and can achieve a depth of 3 m in one year. Vetiver can grow in adverse soil and extreme climatic conditions (Truong, *et al* 1996).

The act of vetiver clumps which are able to slow down the rapid movement of water and wind is really amazing. The 'living wall' or 'living barrier' increases organic matter and moisture in front of the hedgerows and acts as a sieve never allowing any debris to pass through but to accumulate in front of the hedgerow. Both the roots and clumps are so amazing as a 'living dam'. The Vetiver System (VS) was first developed and practiced for soil and water conservation on the farmlands. While this application still plays a vital role in agricultural lands, vetiver's unique morphological, physiological and ecological characteristics, including its tolerance to highly adverse conditions, has played a key role in the area of environmental protection and land rehabilitation. These include tolerance to adverse conditions like: (i) acidity (ii) salinity and sodicity as well as (iii) heavy metal toxicities of arsenic, cadmium, copper, chromium, lead, mercury, nickel, selenium and zinc. Over and above its capacity to tolerate adverse soil conditions, it can also absorb toxic substances like pollutants, pesticides, and heavy metals into its biomass, thereby diluting such toxic substances in the soils and water, making them safe for agriculture and allied activities. One such activity is the use of vetiver to purify eutrophicated water in the lake, leachate from garbage landfill, etc. It can also be used to absorb heavy metals from quarry, and later these valuable metals can be recycled by extraction from the vetiver biomass.

In India vetiver is used as fragrant oil and as traditional medicine since antiquity (Husain *et al* 1984). Multifarious medicinal uses of vetiver are recorded in ancient Ayurvedic treatises by Charaka, Vagbhadananda and others (Masood, 1958; Truong and Baker, 1998; Wong, 2003; Hengchaovanich, 1998; Hengchaovanich and

Nilaweera, 1998; Truong, 1999a; Truong and Baker, 1998; Dalton *et al.* 1996 and Lavania and Lavania, 2009).

Xia, *et al.* (2003) reported several unique charactersistics of this miracle grass and stated that it is an ideal plant for soil and water conservation and erosion controls in tropics and sub tropics. Vetiver can bear up to 120 days of complete submergence, indicating its stronger tolerance compared to many other grasses used for soil and water conservation.

Vetiver leaves are being used for roof thatch, vetiver hut (Lavania, 2003), pre-fabricated vetiver-clay blocks (Hengsadeekul and Nimityongskul, 2003), vetiver clay composite storage bin, cement replacement material (Nimityongskul *et al.* 2003), fiber board, straw bale against insects, bale building and as containers (Thiramongkol and Babpraserth, 2002). Vetiver leaves can be used for cellulosic ethanol production, mushroom culture, furnace fuel, carbon sequestering and handicrafts and aromatic oil production. Vetiver grass has an aesthetic appearance and is sometimes used as an ornamental plant in landscaping (Truong *et al.* 2002).It has found application in pharmaceutical industry because of its antifungal, antibacterial, anticancer, anti-inflammatory and antioxidant activities (Danh, 2010).

2.2 NUTRIENT SOURCES

The root and oil productivity can be enhanced by the application of adequate quantities of plant nutrients through various sources. Vetiver fields have to be continuously replenished through timely application of organic manures, inorganic fertilizers and bio fertilizers.

2.2.1 Organic matter

The organic matter content of soil is intimately related to its productivity. It acts as a store house for nutrients, increases exchange capacity, provides energy for microbial activity, increases water holding capacity, improves soil structure, reduces crusting and increases infiltration, reduces effects of compaction and buffers the soil against changes in acidity, alkalinity and salinity (Tisdale *et al.,* 1993). Efficacy of organic manures such as farm yard manure, compost, oil cakes, green manure, green leaf manure, leaf prunings, etc. have been tested in various crops and cropping systems.

2.2.1.1 In situ composting

Beneficial effects of *in situ* composting in trenches have been reported by several workers. It is quite simple and easy as it gives plant nutrients at the root zone, making the plants healthier in two ways. The plants are nourished with organic matter in trenches leading to the development of a deeper and stronger root system and the plants are able to tolerate biotic and abiotic stresses more effectively and needs less care and attention.

2.2.1.2 Green leaf manuring

Very little information is available on the effects of green leaf manuring in vetiver. However green leaf manure is a potential organic manure which can reduce the cost of cultivation substantially. Value of green leaf manures in improving soil fertility has been recognized since time immemorial. The benefits credited to them include increase in organic matter content and available plant nutrients and improvement in the microbiological and physiological characters. Of these, the role of green leaf manure in supplying plant nutrients, particularly nitrogen is most important. The addition of organic matter in the form of green leaf manures greatly influenced the transformation and mineralization of nitrogen and several essential plant nutrient through its impact on the chemical and biological properties of soil. Upon mineralization green leaves released phosphorus to the soil in plant available form (Bin, 1983 and Watanabea, 1984). Application of green leaf manure to the soil could stimulate formation of ethylene, which acts as a plant hormone for regulating root growth (Smith, 1997)

Singh *et al.* (1992) stated that decomposition and release of mineral nitrogen from green manures were affected by several factors. These include green leaf manure characteristics (nitrogen content, C:N ratio, lignin content, polyphenol content, concentration of organic matter), environmental factors (temperature and soil moisture) and management factors (quantity and method of incorporation of green leaf manure in cropping pattern), etc.

2.3 Bio inoculants

In recent years, bio inoculants have emerged as a supplement to mineral fertilizers and hold a promise to improve the yield of crops. The bio inoculants have positive contributions to soil fertility resulting in an increase in crop yield without causing any type of environmental, water or soil hazards. Among the bio inoculants, Azospirillum, Phosphorus Solubilising Bacteria (PSB), Arbuscular Mycorrhizal Fungi (AMF) and *Fluorescence pseudomonas* have a significant role in crop nutrition.

2.3.1 Azospirillum

Root elongation was improved in a number of crops by Azospirillum inoculation both under green house and field conditions (Barea *et al.* 1973; and Tien *et al.* 1979). Consequent to application, Azospirillum proliferates on the roots and apparently invades the root internal parts. Azospirillum produced plant growth hormones in pure culture. Plant growth responses consequent to inoculation of Azospirillum was due to nitrogen fixation and hormone production by the bacteria (Tien *et al.* 1979). Among diazotrophs, Azospirillum is known to produce significant quantities of plant growth hormones such as gibberellins and cytokinins and auxins like IAA. This will naturally result in better absorption of water and nutrients from the soil. Govindan and Chandy (1985) found that inoculation of Azospirillum induced rooting in pepper cuttings.

Okon *et al.* (1983) proved that initial growth response of Azospirillum inoculation might be more due to the secretion of growth promoting substances than biological nitrogen fixation. The major plant growth hormones produced by Azospirillum includes IAA, IBA, Indole-3-ethanol, Indole-3-methenol, unidentified indole compounds, several gibberellins and cytokinins. They suggested that the presence of Azospirillum in the rhizosphere affects the metabolism of endogenous phytohormones in the plant.

2.3.2 Fluorescence pseudomonas

Fluorescence pseudomonades have emerged as a most promising rhizosphere bacterium (Kloepper *et al.* 1980). This rhizosphere bacterium is being popularized as a potential plant growth promoting rhizobacterium (PGPR). The beneficial effect of PGPR can be through plant growth promotion as evidenced improvements in seedling vigour, seedling weight, root system development and yield. Many rhizobacteria especially *Fluorescence pseudomonades* are known to produce several growth hormones like auxins and cytokinins. This leads to sudden morphological changes in plants like increased root growth, leaf expansion, shoot growth etc. (Garcin *et al.* 2001). *Fluorescence pseudomonades* may promote plant growth by secreting plant hormones like gibberellicacid substances (Suslow, 1982; Lifshtiz *et al.* 1987; Schippers *et al.* 1987 and Weller and Cook, 1983). Enhancement of plant growth has been attributed to the yellow green fluorescent siderophores produced by *Fluorescence pseudomonades* (Kloepper *et al.* 1980). Seed and root inoculation of rhizobacterium promote plant growth by producing plant hormones like auxins and gibberellins (Loper and Scroth, 1986).

2.3.3 Arbescular Mycorrhizal Fungi

Arbuscular Mycorrhizal Fungi are well known for their ability to absorb nutrients particularly phosphorus from soil. Its impact in tropical agriculture is significant compared to temperate regions since phosphorus deficient soils are more wide spread in tropics.

Population of bacteria, actinomycetes, fungi and other microbial organisms in the rhizosphere of mycorrhizal roots are distinctly different from those of non mycorrhizal roots. Bagyaraj and Menge (1978) reported that the vesicular arbuscular mycorrhizal fungus, *Glomus fasciculates,* increased the population of Azotobactor, general rhizosphere bacteria and actinomycetes around mycorrhizal roots compared to control. AMF increased nodulation in legumes, especially in low phosphorus soils and mycorrhizal fungi in plant roots increased plant growth, seed yield, nodule number and weight and acetylene reduction rates over plants that had no mycorrhizal fungus present.

2.4 Dual inoculation of bio inoculants

Bagyaraj (1988) and Linderman (1988) revealed that PSB survived for a longer period in the presence of mycorrhizal fungi. The PSB rendered more phosphorus soluble while AMF enhanced phosphorus uptake. With combined application, there was a synergetic effect on phosphorus supplied and consequent plant growth. PSB also produced hormones and vitamins. The hormones and vitamins synthesized by these organisms might have contributed significantly to AMF development and plant growth.

Sunanthapongsuk (2000) reported the abundance of micro organisms in the rhizosphere of vetiver. Total soil micro organisms and cellulolytic microbes were in the range of 106 to 108 cells g^{-1} of dry soil where as the amount of non symbiotic N-fixing bacteria and phosphorus solubilising microorganisms varied from

101 to 104 cells g^{-1} of soil. The spore load of mycorrhiza ranged from 2.5 to 25.5 spores 100 g^{-1} of soil.

Patiyuth *et al.* (2000) revealed the growth and activity of Azospirillum both outside and inside the vetiver root. Production of plant growth hormone, indole-3- acetic acid (IAA) in the broth to the tune of 30-40 ug ml^{-1} was also revealed.

Inoculation of VA mycorrhiza significantly increased plant biomass and nutrient uptake in vetiver (Techapinyawat *et al.* 2000)

Siripin *et al.* (1996) screened 35 isolates of Nitrogen fixing bacteria from vetiver roots. Nitrogen fixing bacterial inoculation increased vetiver growth and development, particularly by increasing lateral root number, root dry weight, number of tiller, plant height, branch root number, root dry weight, culm dry weight and total plant dry weight.

Techapinyawat *et al.* (2002) studied the effects of three species of AMF; *Acaulospora scrobiculata, Glomus sp., Glomus aggregatum* in combination with phosphate fertilizer on phosphorus uptake of vetiver. They reported that AMF significantly increased phosphorus concentration, phosphorus uptake, percentage phosphorus derived from fertilizer and phosphorus availability in vetiver.

The soil microorganisms associated with vetiver root are nitrogen fixing bacteria, phosphate solubilising microbes, mycorrhizal fungi and cellulolytic microorganism (Siripin, *et al.* 2000). The substances in the exudates of vetiver root served as nutrients and energy sources for the growth of microorganisms in the rhizosphere (Russel, 1982; and Lynch 1990).

2.5 Rain water harvesting

Even though average annual rainfall of Kerala is quite high (3000 mm), most of it is lost as surface runoff because of the highly undulating topography of the region. About 60% of annual rainfall in the state is received during South West monsoon (June - August), 25% during North East monsoon (September-November) and the remaining during summer months. The uneven distribution of rainfall, highly undulating topography and the low water retention capacity of soils cause moisture stress for most of the crops during summer season, which extends from January – May. Rao and Vamadevan (1985) reported that the moisture stress period varies between 14 - 15 weeks in southern parts and 18 - 21 weeks in northern parts of the state. Soil moisture stress prevailing during summer season is one of the major factors affecting the agricultural productivity in the state.

2.5.1 *In situ* rain water harvesting techniques

Under rainfed condition, harvesting of rain water and conservation of soil moisture are the two ways to supplement soil moisture. Harvesting of rain water and *in situ* conservation of soil moisture are the viable alternatives to irrigation. There are many reports about the different ways of rain water harvesting and their effects on growth and yield of fruit crops like plum and sweet oranges (Arora, *et al.* 1987; and Ber and Pathak 2003).

2.5.2 Rain water pits

The most popular and inexpensive rain water harvesting structure for large scale adoption in Kerala is the rain water pits dug out in soil to store rain water which would have otherwise lost by runoff. The collected water percolates into the deeper layers of soil and ultimately recharges the underground water (Nair, *et al.* 2004).

2.5.3 Vertical mulching

Vertical mulching is helpful in *in situ* conservation of rain water for increasing crop yields. Trenches of 20 cm wide and 60-90 cm depth are taken at a spacing of 4 m and filled with sorghum or maize stubbles or stalks prior to onset of rainy season. This will encourage infiltration, check the velocity of running water, conserve soil as well as essential plant nutrient and increase crop yields (Sharma, 2001).

Singh, *et al.* (2013) compared modified trench method of sugarcane planting with other prevailing planting methods for its production potentiality, uptake of nutrients and soil fertility status and reported the superiority of modified trench method of planting in increasing cane yield to the tune of 29 % over control. Significantly highest uptake of N, P, and K (168.60, 87.31, and 254.46 kg ha^{-1}, respectively) were noticed under modified trench method of planting. The fertility status of soil observed initially and after the harvest of sugarcane crop clearly indicated positive effect of modified trench method of planting on soil fertility.

2.5.4 Land configuration

Appropriate land configuration suggests ridges and furrows, broad based beds, raised beds, sunken beds, graded boarder strips, pits, terracing and inter row and inter plot rain water harvesting for *in situ* conservation of soil water and plant nutrient (Singh and Mittal, 2000)

2.5.5 Microsite enrichment

Soil moisture stress arising out of edaphic and climatic constraints limit crop growth and production. Water intake of soil can be increased by improving soil physical properties such as infiltration rate, permeability, bulk density, soil structure, water holding capacity, stable soil aggregates etc. This helps in better crop growth due to conservation of soil moisture and plant nutrient (Acharya and Kapur, 2000). Organic matter as soil amendments plays an important role in soil water conservation and plant growth.

2.5.6 Surface mulching

Kaveeta, *et al.* (2000) studied shoot apex development, rate of leaf primodial initiation and rate of leaf appearance on main stem of four vetiver ecotypes namely; Surat Thani, Ratchaburi, Sri Lanka and Kamphaeng Pheti. The results revealed that the four ecotypes had similar patterns of apex development, but differed substantially in the duration and rate of each development. All four ecotypes had similar linear relationship in the leaf primordial production and performed an exponential relationship with faster leaf production for the first 150 days; thereafter the rate declined.

Roongtanakiat *et al.* (2000) revealed that vetiver mulching conserved top soil moisture and increased available nitrogen, available phosphorus, and extractable potassium. It is also found that one ton of dry vetiver shoot buried at the depth of 10 cm would yield mineral nitrogen, available phosphorus and available potassium, up to 4.4, 2.2, and 20.5 kg while that left on the soil surface would yield only 0.85, 0.74 and 7.20 kg respectively (Chairoj and Roongtankiat, 2004).

Mo (1998) recommended pruning as one of the measures for enhancing production of tillers and formation of healthy leaves. Two prunings in an year, in February (March): and August (September) accelerated tiller formation in vetiver (Xia, 1995). Mulching vetiver prunings on ground surface regulated soil temperature and moisture (Chen and Li, 1998).

The rate of infiltration of water into the soil depends on the intensity and duration of the rainfall, slope of the field, nature of the soil surface and physical characteristics of the soil. Mulching or covering the soil surface with a layer of plant residue is an effective method of conserving water, because it reduces surface runoff and increases infiltration of water into the soil (Ghawi and Battikhi, 1986). Mulch also reduces the depletion of water within the root zone because it suppresses evaporation. In addition, mulching decreases crusting of the soil due to rainfall impact, which reduces erosion by absorbing the kinetic energy of the raindrops (Schwab *et al.*, 1993 and Lal and Stewart, 1995).

Adams (1966) found that mulching with rice straw significantly increased the infiltration of clay pan soils on sloping land. Barnett *et al.* (1967) observed a runoff of 17% of rainfall and 3.4 tons ha^{-1} of soil loss for rice straw mulched plots compared to 38 % and 20.2 tons ha^{-1} for an unmulched plot. Lattanzi *et al.* (1974) showed that interill erosion was reduced by approximately 40 % when wheat straw mulch was applied at the rate of 6 tons ha^{-1} and by an estimated 80% at a rate of 9.2 tons ha^{-1}. Meyer (1961) found that soil loss from plots covered with shredded corn stalks was about one-half of unmulched plots. Meyer *et al.* (1970) reported that 0.5 tons ha^{-1} of rice straw mulch can reduce soil loss by one-third of that with no mulch cover, and at 5 tons ha^{-1} could reduce soil loss by 95%. Khan *et al.* (1988) found mulching with rice straw to be more effective than using cover crop. Lal (1979) found mulching tilled soil with 4–6 tons ha^{-1} of rice straw to be effective in reducing soil loss and runoff on slopes ranging from 1% to 15% and that the effectiveness of no-tillage in preventing runoff and erosion was comparable to applying 4–6 tons ha^{-1} of rice straw mulch. Mulching materials in the tropics include leafy crop residues such as sugarcane trash (*Saccharium esculenta*) or banana (*Musa parasidica*) leaves and easily grown bulky fodder crops such as elephant or guinea grass.

2.6 Crop Residue Management

Singh, *et al.* (1992) described in detail about crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the Tropics. Crop residues, when managed correctly can improve soil organic matter dynamics and nutrient cycling, thereby creating a rather favorable environment for plant growth. Viable option is to retain residue in the field; burning should be avoided. Residues rich in lignin and polyphenol contents experience the lowest decay. Factors that control carbon decomposition also affect the nitrogen mineralization from the crop residues. Decomposition of poor-quality residues with low nitrogen contents, high C:N ratios, and high lignin and polyphenol contents generally results in microbial immobilization of soil and fertilizer nitrogen. Nutrient cycling in the soil–plant ecosystem is an essential component of sustainable productive agricultural enterprise. Incorporation of crop residues alters the soil environment that in turn influences the microbial population and activity in the soil and subsequent nutrient transformations.

Returning crop residues to the soil improved soil quality and productivity through favorable effects on soil properties (Lal and Stewart, 1995). Favorable effects of residue mulching on soil organic carbon (SOC), water retention and per cent water-stable aggregates have been reported for the surface layer (Duiker and Lal, 1999 and Havlin *et al.* 1990). Application of crop residue mulches increased SOC content (Havlin *et al.* 1990; Paustian *et al.* 1997 and Saroa and Lal, 2003). Duiker and Lal (1999) reported a positive linear effect of mulch application rate on SOC concentration.

The effect of crop residue on soil organic matter (SOM) content is highly related to the amount and only weakly to the type of residue applied. Reicosky *et al.* (1995) reported a strong relationship between residue amounts and SOM in the 0–15 cm layer. Conservation of soil moisture is one of the major advantages of mulch farming system. Mulching protects the soil from water erosion by reducing the rain drop impact. A partial covering of mulch residue on the soil could strongly affect runoff dynamics, and reduce runoff amount (Findeling *et al.* 2003 and Rees *et al.* 2002). Straw mulch increased soil moisture storage (Ji and Unger, 2001). Crop residues at the soil surface shade the soil, serve as a vapour barrier against moisture losses from the soil, slow surface runoff and increase infiltration. Rathore *et al.*

(1998) observed that more water was conserved in the soil profile during the early growth period with straw mulch than without it. Subsequent uptake of conserved soil moisture moderated plant water status, soil temperature and soil mechanical resistance, leading to better root growth and higher grain yields.

Mulching effects on soil bulk density are often variable. While some researchers have observed reduced soil bulk density under mulch (Unger and Jones, 1998), others have observed increased bulk density (Bottenberg *et al.* 1999) and yet others no mulch effect on bulk density (Blevin *et al.* 1983, Acosta *et al.* 1999 and Duiker and Lal, 1999). The effects of mulching on bulk density may vary due to soil type, antecedent soil properties, type of mulch, climate and land use.

2.7 Soil moisture

Soil excavation technique (Salam *et al.* 1993) showed that 88 % of the active roots of vetiver existed at a depth of 40 cm and 92 % at a horizontal radius of 20 cm. Similar results were reported by Yoon *et al.* (1996).

Wide variations in water use rate have been reported by several workers. The evapo transpiration rate of vetiver widely varied from 43 mm day^{-1} (Jones 2005), 3.8 mm day^{-1} in summer and 1.9 mm day^{-1} in winter (Percy and Truong 2005) and 8-14 mm day^{-1} (Truong and Smeal, 2003). It possessed a lace work root system that is abundant, complex and extensive (Chomchalow and Hicks, 2001), which grew upto 3-4 m in the first year of planting (Hengchaovanich, 1998) and acquired a total length of 7 m after 36 months (Lavania, 2003).

2.8 Physiological parameters

The root:shoot ratio is a highly representative indicator of environmental stress that is encountered by plants (Chiu *et al.* 2006).

2.9 Uptake of nutrients

When vetiver hedge rows was established at every 2 m interval, 100 m hedge rows produced 800-1500 kg fresh prunings resulting in 4-7.5 tons of prunings ha^{-1} $year^{-1}$. When it was used as green manure, the soil organic matter, bulk density, porosity, and carbon, nitrogen and potassium contents improved considerably and 34.8% increase in corn yield was reported (Lu and Zhong, 1998).

Vetiver shows high tolerance to Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se, and Zn in the soil (Truong 1999a; and Truong and Baker 1998). High tolerance to herbicides and pesticides (Cull *et al.* 2002; Pinthong *et al.* 1998) were also reported in vetiver. Vetiver expressed high efficiency in absorbing dissolved N, P, Hg, Cd and Pb from polluted water (Pinthong *et al.* 1998; Sripen *et al.* 1996).

Cultivation of vetiver as a sole crop and in mixed cropping with cover crops in laterite soil, improved soil properties such as pH, organic matter, available phosphorus, extractable potassium, aggregate stability, bulk density, permeability and available water holding capacity (Tantachasatid, 2003).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

Two separate experiments were conducted at the Instructional farm attached to the College of Agriculture, Padannakkad to develop agro techniques for quality planting material production and to evolve methods for enhancing root and oil yield in vetiver. The nursery trial was conducted to study the effect of single, dual and combined application of microbial inoculants on quality planting material production during the period from 27.12.2011 to 27.03.2012. A field experiment was also conducted to evolve methods for achieving higher root and oil productivity in vetiver with special reference to climate change mitigation from 09.04.2012 to 09.04.2013.

The materials used and methodologies followed for the experiments are presented in this chapter.

3.1 MATERIALS

3.1.1 Experimental Site

The experiments were conducted at the Instructional Farm attached to 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 of less than 20 m above MSL.

3.1.2 Soil

The soil of the experimental site is sandy (Hosdurg series). The mechanical composition and moisture characteristics of the soil are summarized in Table 1 and chemical properties in Table 2.

3.1.3 Climate and Season

The weather data recorded during April 2012 to March 2013 are given in Appendix I and graphically presented in Fig. 1. The abstract of weather data is given in Table 3.

Table 1. Mechanical composition and moisture characteristics of soil

Particulars	Content	Method
A. Mechanical composition		
Coarse sand, %	30.28	
Fine sand, %	57.65	Bouyoucos hydrometer method
Silt, %	7.5	(Bouyoucos, 1962)
Clay, %	4.57	
B. Soil moisture characteristics		
Particle density, g cc $^{-1}$	2.16	Pycnometer method (Black, 1965)
Bulk density, g cc $^{-1}$	1.34	
Maximum water holding capacity, % (w/w)	18.2	Core method (Gupta and Dakshinamoorthi, 1980)
Porosity, % (v/v)	47	
Field capacity, % (w/w)	16	
Permanent wilting point, % (w/w)	10	

Table 2. Chemical properties of soil

Particulars	Content	Method
Organic carbon, %	0.38	Walkley and Black rapid titration method (Jackson,1973)
Organic matter, %	0.5	
Available nitrogen, kg ha^{-1}	52.8	Alkaline $KMnO_4$ method (Subbiah and Asija, 1956)
Available phosphorus, kg ha^{-1} as P	14.3	Bray's colourimetric method (Jackson, 1973)
Available potassium, kg ha^{-1} as K	22.1	Ammonium acetate method (Jackson, 1973)
Soil reaction (pH)	5.3	pH meter with glass electrode (Jackson, 1973)

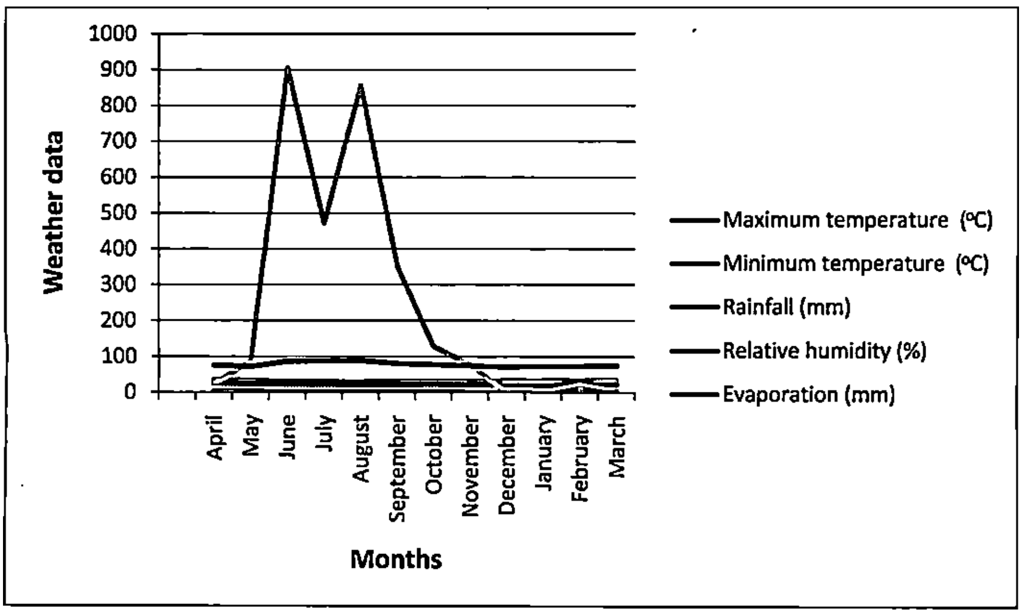


Fig. 1 Weather data during the Crop period (April '12 to April'13)

Table 3. Abstract of the weather data during the experimental period, April 2012 to March 2013

Weather elements	Range	Mean
Maximum temperature, ^{0}C	29.2 - 34.6	31.89
Minimum temperature, ^{0}C	20.0 – 25.6	22.68
Annual rainfall, mm	----	2924.8
Relative humidity, %	71.6 – 89.3	78.47
Monthly evaporation, mm	2.3 – 4.9	3.58

3.2 METHODS

3.2.1 Nursery Trial – Bio inoculants for Quality Planting Material Production

The main objective of the trial was to study the effect of single, dual and combined application of microbial inoculants on quality planting material production in vetiver.

3.2.1.1 Design and Layout

Design: CRD (Completely Randomized Design)

Replication: 3

Number of plants per treatment: 25

Layout plan is given in Fig 2.

3.2.1.2 Treatments

B_1-Single inoculation with *Azospirillum*

B_2-Single inoculation with PSB

B_3-Single inoculation with AMF

B_4-Single inoculation with Fluorescent Pseudomonads (FP)

B_5-Dual inoculation with Azospirillum and PSB

B_6-Dual inoculation with Azospirillum and AMF

B_7-Dual inoculation with Azospirillum and FP

B_8-Combined inoculation with Azospirillum, PSB and AMF

B_9-Combined inoculation with Azospirillum, PSB, AMF and FP

B_{10}-Control (No inoculation)

3.3 NURSERY DETAILS

3.3.1 Collection of Planting Material

A high yielding cultivar of vetiver brought from an approved SHM (State Horticulture Mission) nursery near Agasthyakoodam in Thiruvananthapuram district was multiplied at the Instructional farm, Padannakkad and used for the trial.

3.3.2 Imposition of Treatments

The treatments were imposed while planting vetiver slips in polythene bags in December 2011.

3.3.2.1 Poly Bags

Poly bags of size 15 cm x 10 cm to hold 1000 cc of rooting medium were selected for the trial.

3.3.2.1.1 Potting Mixture

Soil, sand and cow dung were mixed in equal proportion to prepare potting mixture.

3.3.2.2 Bioinoculants

3.3.2.2.1 Single inoculation with *Azospirillum*

Fresh culture of *Azospirillum brasilience* (acid tolerant strain) with a spore activity of 10^8 g^{-1} of culture obtained from the department of agricultural microbiology, UAS (university of Agricultural Sciences), Dharward, was thoroughly mixed with cow dung slurry and basal part of the slips were dipped in the slurry for 30 minutes.

3.3.2.2.2 Single inoculation with PSB (Phosphorus Solubilising Bacteria)

The basal portions of the slips were dipped in loose water slurry of Phosphorus Solubilising Bacteria PSB (500 g in 2.5 litre of water) for 20 minutes prior to transplanting.

3.3.2.2.3 Single inoculation with AMF (Arbuscular Mycorrhizal Fungi)

Inoculum of AMF containing more than 15 spores g^{-1} of air dried soil and infected root fragments of guinea grass (*Panicum maximum*) was collected from the department of agricultural microbiology, College of Agriculture, Padannakkad. The species used was *Glomus monosporum.* A planting hole of 5 cm depth and 2 cm width was made in already filled in polythene bag and inoculam was applied at the rate of 5 gram per hole and slips planted in such a way that the root surface had intimate contact with the inoculum.

3.3.2.2.4 Single inoculation with FP (*Fluorescent Pseudomonads*)

Fluorescent Pseudomonads exhibits root inducing property. Fresh culture of FP was collected from department of agricultural microbiology, College of

Agriculture, Padannakkad. It was thoroughly mixed with cow dung slurry and basal parts of the slips were dipped in the slurry for 30 minutes before planting.

3.3.2.2.5 Dual inoculation with Azospirillum and PSB

Vetiver slips were inoculated with Azospirillum and Phosphorus Solubilising Bacteria as above and then planted in planting hole.

3.3.2.2.6 Dual inoculation with Azospirillum and AMF

Azospirillum inoculated vetiver slips were planted in planting hole treated with Arbuscular Mycorrhizal Fungi as in single inoculation of Arbuscular Mycorrhizal Fungi.

3.3.2.2.7 Dual inoculation with Azospirillum and FP

Azospirillum inoculated vetiver slips were planted in planting hole as in single inoculation. One week after planting the slips, *Fluorescent Pseudomonads* mixed with vermicompost was broadcast and incorporated in rhizosphere.

3.3.2.2.8 Combined inoculation with Azospirillum, PSB and AMF

Vetiver slips were inoculated with Azospirillum and Phosphorus Solubilising Bacteria and planted in planting hole treated with Arbuscular Mycorrhizal Fungi as in single inoculation of AMF.

3.3.2.2.9 Combined inoculation with Azospirillum, PSB, AMF and FP

Vetiver slips were inoculated with Azospirillum and Phosphorus Solubilising Bacteria, and planted in planting hole treated with Arbuscular Mycorrhizal Fungi as in single inoculation of AMF. One week after planting the slips, *Fluorescent Pseudomonads* thoroughly mixed with vermicompost was broadcast and mixed with rhizosphere soil.

3.3.2.2.10 Control

Saplings were raised without the application of bioinoculants.

3.3.3 After Care

The bags were placed under partial shade in coconut garden and were irrigated as and when required.

3.4 OBSERVATIONS

Observations were recorded at monthly intervals for a period of three months from randomly selected five plants and mean values worked out. The methods followed for recording observations are furnished below.

3.4.1 Morphological characters

3.4.1.1 Plant height

The height was measured from the base of the plant to the tip of the tallest leaf and expressed in cm.

3.4.1.2 Number of leaves

Number of functional leaves per hill was counted from the observation plants and mean values recorded.

3.4.2 Root parameters

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

3.4.2.1 Root number

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

3.4.2.2 Root Length

Both vertical and lateral length of the roots were measured and expressed in cm.

3.4.2.3 Root Spread

Measured the maximum spread of roots and expressed in cm.

3.4.2.4 Root Weight

The roots were washed, cleaned, dried in an oven at 75 ^{0}C to a constant weight. The weights were expressed as g plant^{-1}.

3.4.3 Physiological parameters

Third fully opened leaf from the top was taken as index leaf for recording physiological parameters.

3.4.3.1 Relative Leaf Water Content (RLWC)

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

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

3.4.4 Growth Indices

3.4.4.1 Root Growth Potential

$$RGP = \frac{\text{Root length}}{\text{Number of roots}}$$

3.4.4.2 Sturdiness Quotient

$$SQ = \frac{\text{Plant height (cm)}}{\text{Collar girth (cm)}}$$

3.4.4.3 Seedling Growth Potential

$$SGP = \frac{\text{Total dry matter production}}{\text{SQ + Shoot: root ratio}}$$

3.4.4.4 Relative Growth Rate (RGR)

Relative growth rate is the amount of dry matter produced per unit amount of dry matter present in it. It can be calculated as,

$$RGR = \frac{\text{Loge W2} - \text{W1}}{T_2 - T_1}$$

3.4.5 Total dry matter production

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

3.4.6 Microbiological observations

The standard procedures were followed for the estimation of Azospirillum (Dobereiner *et al*, 1976), Phosphorus solubilising bacteria (Sundara and Sinha, 1963), Arbuscular mycorrhizal fungi (Phillips, 1970) and *Fluorescent Pseudomonads* (King *et al, 1954*).

3.4.7 Statistical analysis

The analysis of variance was done using General linear model's procedure of statistical analysis software (SAS) (Hatcher, 2003).

3.5 FIELD EXPERIMENT

The main objective of this experiment was to develop eco-friendly techniques to achieve higher root and oil productivity in vetiver with special reference to climate change mitigation.

3.5.1 Design and Lay out

Design: Factorial RBD

No.of treatment combinations: 12+2

Replication: 2

Plot size: 2 m x 2 m

Layout plan is given in Fig. 2.

3.5.2 Treatments

Factor A. Row zone management (trenches)

T_1-*In situ* composting in trenches

T_2-*In situ* composting in trenches + Stubble mulching

T_3-*In situ* composting in trenches + Stubble mulching + Summer irrigation at 40 mm CPE (Cumulative Pan Evaporation)

T_4-*In situ* composting in trenches + Stubble mulching + Summer irrigation at 80 mm CPE

Factor B. Inter-row zone management (broad beds)

B_1-Multiple cropping (Harvesting and replanting at 4 and 8 MAP)

B_2-Double cropping (Harvesting and replanting at 8 MAP)

B_3-Monocropping (Harvesting at 12 MAP)

Control

S_1-Sole cropping (Normal Row Planting – PoP, KAU)

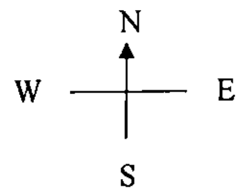
S_2-Sole cropping (Paired Row Planting – PoP, KAU)

3.5.3 Treatment Combinations (4 x 3) + 2

The treatment combinations are listed in Table 4.

Table 4. Treatment combinations

No.	Treatment combinations
1	T_1B_1 - *In situ* composting in trenches and Multiple cropping (Harvesting and replanting at 4 and 8 MAP)
2	T_1B_2 - *In situ* composting in trenches and Double cropping (Harvesting and replanting at 8 MAP)
3	T_1B_3 - *In situ* composting in trenches and Mono cropping (Harvesting at 12 MAP)
4	T_2B_1 - *In situ* composting in trenches + stubble mulching and Multiple cropping (Harvesting and replanting at 4 and 8 MAP)
5	T_2B_2 - *In situ* composting in trenches + stubble mulching and Double cropping (Harvesting and replanting at 8 MAP)
6	T_2B_3 - *In situ* composting in trenches + stubble mulching and Mono cropping (Harvesting at 12 MAP)
7	T_3B_1 - *In situ* composting in trenches + stubble mulching + summer irrigation at 40 mm CPE and Multiple cropping (Harvesting and replanting at 4 and 8 MAP)
8	T_3B_2 - *In situ* composting in trenches + stubble mulching + summer irrigation at 40 mm CPE and Double cropping (Harvesting and replanting at 8 MAP)
9	T_3B_3 - *In situ* composting in trenches + stubble mulching + summer irrigation at 40 mm CPE and Mono cropping (Harvesting at 12 MAP)
10	T_4B_1 - *In situ* composting in trenches + stubble mulching + summer irrigation at 80 mm CPE and Multiple cropping (Harvesting and replanting at 4 and 8 MAP)
11	T_4B_2 - *In situ* composting in trenches + stubble mulching + summer irrigation at 80 mm CPE and Double cropping (Harvesting and replanting at 8 MAP)
12	T_4B_3 - *In situ* composting in trenches + stubble mulching + summer irrigation at 80 mm CPE and Mono cropping (Harvesting at 12 MAP)
Controls	
1	Sole cropping (Normal Row Planting – PoP, KAU)
2	Sole cropping (Paired Row Planting – PoP, KAU)



1. Techniques for quality planting material production.

B_8	B_2	B_9	B_4	B_{10}	B_6	B_5	B_7	B_3	B_1
B_{10}	B_5	B_7	B_3	B_1	B_4	B_6	B_9	B_2	B_8
B_3	B_7	B_1	B_4	B_8	B_5	B_{10}	B_2	B_6	B_9

2. Multiple cropping and micro site enrichment techniques for row and inter-row zone management

T_1B_2	T_3B_3	NRP	T_4B_2	T_1B_3	T_2B_2	T_4B_1
T_1B_1	T_2B_1	T_4B_3	T_3B_1	T_2B_3	PRP	T_3B_2
T_4B_1	T_3B_3	T_4B_2	T_1B_2	T_3B_2	T_2B_3	T_2B_1
T_1B_3	NRP	T_4B_3	T_2B_2	T_1B_1	PRP	T_3B_1

Fig 2. Layout plans

3.6 FIELD CULTURE

3.6.1 Land Preparation

The selected area was tilled, stubbles removed, clods broken, levelled and laid into plots as per the layout plan.

3.6.2 Planting

Details of the planting materials used are furnished under the section 3.3.1. Vetiver slips treated with the most promising bio inoculant, PSB in respect of single inoculation with PSB based on results of the nursery trial conducted were planted in the trenches by following paired row planting pattern in the main field (Trenches : 25 cm between two rows making up a pair, 100 cm between two such paired rows; Broad bed : 12.5 cm between two rows making up a pair and 12.5 cm between plants with in the row, 50 cm between two such paired rows) as per the technical programme.

3.6.3 Imposition of Treatments

Treatments were imposed as follows

3.6.3.1 Row zone management

3.6.3.1.1 In situ composting

Trenches of 200 cm length 50 cm width and 30 cm depth were taken at a spacing of 25 x 25 cm. The excavated soil was used for making broad beds in between trenches. Dried leaves (10 kg / trench) were filled in trenches and that were sprinkled with cow dung slurry and covered with soil 21 days prior to transplanting of vetiver slips. Optimum moisture level was maintained in the trenches to facilitate the composting process without interfering vetiver establishment.

3.6.3.1.2 Stubble mulching

Vetiver planted in the trenches was pruned at a height of 5 cm from the ground level at four and eight months after transplanting. Vetiver planted in the broad beds was harvested by uprooting at four and eight months after planting as per the technical programme and collected the leaf biomass after separating the root system. Biomass available both from the trenches and broad beds was chopped, quantified and used for stubble mulching in the trenches.

3.6.3.1.3 Irrigation scheduling

Irrigation was scheduled based on CPE (Cumulative Pan Evaporation) as per technical programme. The following formula was used for calculating the volume of water required for irrigation.

Volume of water required = Depth of irrigation water x wetted area

Details of irrigation during the experimental period are given in Table 5.

Pretreatment irrigation was given to bring the soil moisture content to field capacity. The quantity of water required per plot to bring the area to field capacity was calculated on the basis of the following formula by taking the depth of irrigation as 6.03 cm.

$$d = \frac{FC - PWP}{100} \times \frac{50}{100} \times Asi \times Di$$

Where, d = depth of irrigation water in mm.

FC = Field capacity, %

PWP = Permanent wilting point, %

Asi = Apparent specific gravity, g cc^{-1}

Di = Depth of root zone, cm

Table5.Details of irrigation given during the experimental period (04.2012 to 4.2013)

Treatments	No. of irrigations	Irrigation requirement (l /plot)	Pretreatment irrigation (l /plot)	Effective rainfall (l /plot)	Total water requirement (l /plot)
T_1B_1	23	5520	240	2000	7760
T_1B_2	23	5520	240	2000	7760
T_1B_3	23	5520	240	2000	7760
T_2B_1	23	5520	240	2000	7760
T_2B_2	23	5520	240	2000	7760
T_2B_3	23	5520	240	2000	7760
T_3B_1	40	9600	240	1200	11040
T_3B_2	40	9600	240	1200	11040
T_3B_3	40	9600	240	1200	11040
T_4B_1	27	6480	240	1600	8320
T_4B_2	27	6480	240	1600	8320
T_4B_3	27	6480	240	1600	8320
SNC	23	5520	240	2000	7760
SPC	23	5520	240	2000	7760

T – Trenches, B – Broad Beds, SNC – Sole Normal row Control, SPC – Sole Paired row Control

3.6.3.2 Inter row zone management

The space between the two trenches was made into a broad bed of size 100 cm x 200 cm and utilized for high density planting of vetiver at a spacing of 12.5 cm between two rows making up a pair and 12.5 cm between plants with in the row leaving 50 cm between two such paired rows.

3.6.3.2.1 Multiple cropping

Vetiver slips planted on the broad beds were harvested by uprooting and replanted at four and eight months after planting and leaf biomass recycled for stubble mulching. A total of three crops were taken during the one year period of experimentation.

3.6.3.2.2 Double cropping

Vetiver slips planted on the broad beds were harvested by uprooting and replanted at eight months after planting and leaf biomass recycled for stubble mulching. A total of two crops were taken during the one year period of experimentation.

3.6.3.2.3 Mono cropping

Crop was harvested at twelve months after planting.

3.6.3.3 Control

Sole cropping – Normal row planting

Vetiver slips were planted at a spacing of 50 x 50 cm and maintained as per Package of Practices recommendations of crops of Kerala Agricultural University.

Sole cropping – Paired row planting

Vetiver slips were planted in paired rows as discussed under section 3.6.2 and the crop maintained as discussed in the section 3.6.3.

3.7 OBSERVATIONS

3.7.1 Morphological Characters

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

Observations on plant height, number of leaves and tiller production were recorded as discussed under sections 3.4.1.

3.7.2 Root Studies

The procedure followed for root studies are furnished under sections 3.4.2. Root number, root length, root spread and root weight were recorded.

3.7.3 Physiological and bio chemical parameters

3.7.3.1 Relative Leaf Water Content (RLWC)

The method outlined under section 3.4.3.1 was followed for the estimation of leaf water content.

3.7.3.2 Chlorophyll content

Chlorophyll content was estimated using a SPAD meter (Model SPAD 502).

3.7.4 Dry matter production and partitioning

The plants were uprooted at four and eight months after planting and at the time of harvest and the roots and shoot portions were separated in each sampling and dried to constant weight.

The dry weight of root and shoot portion were recorded separately and expressed in g $plant^{-1}$. Total dry matter production was worked out from shoot and root dry matter and estimated dry matter partitioning.

3.7.5 Soil moisture studies

3.7.5.1 Soil moisture

Soil sampling was done using a screw auger at a distance of 15 cm away from the base of the plant to a depth of 20 cm just before and 48 hours after irrigation and the soil moisture worked out gravimetrically.

3.7.5.2 Consumptive use (Cu) of Water

Consumptive use of water by vetiver under different treatments was worked out using the formula suggested by Dasthane (1972).

$$Cu = \sum_{1}^{N} (Ep \times 0.6) + \sum_{1}^{n} \frac{(Mai - Mbi)}{100} \times Asi \times Di + ER$$

Where, Cu = Consumptive use of water in mm.

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

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

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

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

Asi = Apparent specific gravity of ith layer of soil, g cc^{-1}

Di = 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 soil sampling.

3.7.5.3 Irrigation Requirement

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

3.7.5.4 Water Use Efficiency

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

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

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

3.7.5.5 Water Productivity (WP)

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

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

3.7.5.6 Crop Coefficient (Kc)

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

3.7.6 Root yield

The plants were uprooted from each plot after one year of planting and recorded the total root dry weight from each plot separately.

3.7.7 Oil content

Vetiver roots were washed, dried and chopped into small bits. Oil content was estimated by using modified Clevenger apparatus as suggested by Pruthi (1999) and expressed in per cent.

3.7.8 Nutrient uptake studies

Nutrient uptake was calculated by multiplying per cent nutrient content with total dry matter production.

3.7.9 Economics

3.7.9.1 Cost of cultivation

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

3.7.9.2 Gross returns

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

3.7.9.3 Net returns

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

3.7.9.4 Benefit Cost Ratio (BCR)

Benefit cost ratio was calculated as follows

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

3.7.10 Statistical analysis

The procedure outlined under the section 3.4.7 was followed for the conduct of statistical analysis.

RESULTS

4. RESULTS

Two separate experiments were carried out at the Instructional Farm, College of Agriculture, Padannakkad to study the effect of single, dual and combined application of microbial inoculants on quality planting material production and to develop eco-friendly techniques for achieving higher root and oil productivity in vetiver with special reference to climate change mitigation.

4.1 PART A: BIO INOCULANTS FOR QUALITY PLANTING MATERIAL PRODUCTION

A pot culture trial was laid out in completely randomized design (CRD) with ten treatments and three replications to study the effect of single, dual, and combined application of Azospirillum, phosphorus solubilising bacteria, arbuscular mycorrhizal fungi and fluorescent pseudomonas on quality planting material production in vetiver and the results obtained are furnished below.

4.1.1 Morphological characters

The effect of single, dual, and combined inoculation of bio inoculants on morphological characters, *viz,* height and leaf number of vetiver saplings at monthly intervals are given in Table 6.

The effect of bio inoculants on sapling height was evident at all stages of growth and single inoculation with phosphorus solubilising bacteria (B_1) significantly enhanced sapling height after second and third month of planting. Compared to uninoculated control, the increase in height were 38.92 per cent and 21.4 per cent respectively at second and third months after planting. Inoculation with arbuscular mycorrhizal fungi (B_3) significantly reduced plant height both at second and third month after planting and reduction in height were to the tune of 8.61 per cent and 34.29 per cent respectively compared to control.

Table 6. Plant height and leaf number of vetiver saplings at 1, 2 and 3 MAP as influenced by single, dual and combined application of bio inoculants in nursery

Treatments	Plant height (cm)			Leaf number		
	1 MAP	2 MAP	3 MAP	1MAP	2 MAP	3 MAP
B_1	73.97	134.97	189.00	6	7	9
B_2	95.10	140.17	192.23	6	9	11
B_3	85.30	92.90	117.90	6	12	14
B_4	89.93	102.43	163.90	6	12	13
B_5	83.13	119.10	172.70	6	9	11
B_6	90.97	120.17	163.73	6	7	9
B_7	90.08	112.70	170.17	6	6	10
B_8	72.27	117.10	174.17	5	10	12
B_9	86.27	138.10	183.10	6	7	10
B_{10}	96.93	100.90	158.33	7	7	10
CV (%)	9.12	13.32	12.01	10.19	23.38	17.02
SE	0.09	0.08	0.1	0.26	0.32	0.35
CD (0.05)	0.35	0.29	0.36	NS	1.16	1.28

MAP – Months After Planting NS – Not significant

Application of bioinoculants had no significant influence on leaf number after one month of planting. However, the effect was significant at later stages of growth and single inoculation with arbuscular mycorrhizal fungi (B_3) which was on par with single inoculation with fluorescent pseudomonas (B_4) produced more number of functional leaves. Increase was tune of 71.4 and 40.0 per cent compared to uninoculated control at second and third month of planting.

4.1.2 Root parameters

Root parameters, *viz*, root number, root length and root spread as influenced by single, dual and combined application of bioinoculants at first, second and third month after planting are presented in Table 7.

Significant variations in root parameters were observed at all stages of growth. The effect of single inoculation with phosphorus solubilising bacteria (B_1) in increasing root number was significant after two months. Compared to uninoculated control (B_{10}), the increase in root number at second and third month were 31.25 per cent and 19.05 per cent respectively. Dual inoculation with Azospirillum and phosphorus solubilising bacteria (B_5) drastically reduced root number at second and third month after planting.

Contrary to root number, root length was remarkably influenced by dual inoculation with Azospirillum and fluorescent pseudomonas at all stages of growth and it was significantly different from all other treatments compared to uninoculated control. 70.36 per cent, 90.03 per cent and 70.65 per cent increase in root length were observed at first, second and third month after planting respectively. When planting materials were inoculated with Azospirillum and phosphorus solubilising bacteria, considerable reduction in root length was evident throughout the nursery period.

Table 7. Root parameters of vetiver saplings at 1, 2 and 3 MAP as influenced by single, dual and combined application of bio inoculants in nursery

Treatments	Root number			Root length (cm)			Root spread (cm)		
	1 MAP	2 MAP	3 MAP	1 MAP	2 MAP	3 MAP	1 MAP	2 MAP	3 MAP
B_1	13	20	23	32.00	46.10	58.33	7.03	10.30	13.10
B_2	14	21	25	35.63	62.93	77.37	5.13	11.50	16.17
B_3	11	13	17	45.93	47.67	59.33	5.27	9.33	11.57
B_4	13	16	19	29.00	35.43	45.33	6.40	5.50	9.77
B_5	9	13	15	18.90	29.90	39.30	4.80	9.00	10.53
B_6	12	14	17	34.67	42.80	49.53	3.63	7.50	8.80
B_7	8	18	21	62.30	85.00	91.93	3.60	6.57	8.03
B_8	12	15	17	46.13	55.27	63.47	6.13	8.33	11.97
B_9	8	15	18	26.73	46.63	56.60	5.53	9.30	12.90
B_{10}	14	16	21	36.57	44.73	53.87	4.60	8.40	9.67
CV (%)	20.34	16.78	15.95	31.96	30.04	25.02	23.77	20.78	21.19
SE	0.34	0.29	0.38	0.34	0.32	0.43	0.34	0.32	0.28
CD (0.05)	1.24	1.07	1.39	1.23	1.16	1.54	1.24	1.17	1.03

MAP – Months After Planting

One month after planting, Azospirillum (B_1) which was on par with single inoculation with fluorescent pseudomonas (B_4) and combined inoculation with Azospirillum, phosphorus solubilising bacteria, arbuscular mycorrhizal fungi (B_8), significantly increased root spread after two months. However, single inoculation with phosphorus solubilising bacteria (B_2) which was significantly different from all other treatments recorded the highest root spread at second and third month after planting and the increase over control was 36.90 per cent and 67.22 per cent respectively.

4.1.3 Biomass accumulation and partitioning

Mean shoot and root weight and total biomass accumulation as influenced by single, dual, and combined application of bioinoculants at first, second and third month after planting are furnished in Table 8.

Single inoculation with phosphorus solubilising bacteria significantly improved shoot weight throughout the nursery period and per cent increase over control were 224.84, 113.20 and 59.47 at first, second and third month after planting respectively. However, when phosphorus solubilising bacteria was combined with Azospirillum, shoot weight drastically declined at second and third month after planting.

A similar trend was observed with respect to root weight and biomass accumulation.

4.1.4 Physiological parameters

The influence of single, dual, and combined application of bioinoculants on physiological parameters namely relative leaf water content at first, second and third month after planting; and relative growth rate at second and third month after planting are furnished in Table 9.

Table 8. Biomass accumulation in vetiver saplings at 1, 2 and 3 MAP as influenced by single, dual and combined application of bio inoculants in nursery

Treatments	Shoot (g/plant)			Roots (g/plant)			Total biomass(g/plant)		
	1 MAP	2 MAP	3 MAP	1 MAP	2 MAP	3 MAP	1 MAP	2 MAP	3 MAP
B_1	3.47	7.20	12.22	0.74	1.80	2.85	4.21	9	15.07
B_2	4.97	8.72	13.22	1.12	2.06	4.03	6.09	10.78	17.25
B_3	1.70	3.70	5.43	0.63	1.47	2.79	2.33	5.17	8.22
B_4	2.10	4.87	6.73	0.65	1.08	2.62	2.75	5.95	9.35
B_5	1.33	2.48	4.28	0.30	0.40	1.60	1.63	2.88	5.88
B_6	2.97	5.36	8.30	0.70	1.86	2.67	3.67	7.22	10.97
B_7	2.30	5.01	9.01	0.40	0.89	1.83	2.7	5.9	10.84
B_8	2.13	5.19	8.63	0.45	1.08	2.98	2.58	6.27	11.61
B_9	3.17	6.47	10.18	0.63	1.69	3.03	3.8	8.16	13.21
B_{10}	1.53	4.09	8.29	0.66	1.16	2.95	2.19	5.25	11.24
CV (%)	42.41	33.12	31.48	35.02	37.49	24.59	39.65	32.73	28.06
SE	0.13	0.18	0.25	0.02	0.06	0.11	0.13	0.20	0.26
CD (0.05)	0.489	0.638	0.905	0.0827	0.2083	0.385	0.483	0.729	0.929

MAP – Months After Planting

Table 9 RLWC and RGR of vetiver saplings at 1, 2 and 3 MAP as influenced by single, dual and combined application of bio inoculants in nursery

Treatments	RLWC (%)			RGR (g g-1 d-1)	
	1 MAP	2 MAP	3 MAP	2 MAP	3 MAP
B_1	16.68	17.26	23.59	1.14	2.58
B_2	17.72	21.81	20.28	0.77	1.83
B_3	3.41	5.58	11.96	1.22	2.53
B_4	8.57	11.38	17.28	1.164	2.4
B_5	10.36	8.03	10.11	0.77	2.61
B_6	11.84	10.48	11.32	0.96	1.99
B_7	15.98	13.97	26.49	1.19	3.02
B_8	16.13	15.29	30.81	1.43	3.5
B_9	8.74	6.07	17.59	1.15	2.48
B_{10}	6.21	12.57	18.98	1.39	4.13
CV (%)	42.68	41.70	39.03	25.61	27.50
SE	0.80	0.79	1.94	0.102	0.18
CD (0.05)	2.91	2.85	6.99	0.37	0.67

MAP – Months After Planting

RLWC- Relative Leaf Water Content   RGR- Relative Growth Rate

At one and two months after planting, phosphorus solubilising bacteria registered highest relative leaf water contents followed by Azospirillum. Arbuscular mycorrhizal fungi at both stages of growth recorded the lowest relative leaf water content. At three months after planting Azospirillum + phosphorus solubilising bacteria + arbuscular mycorrhizal fungi (B_8) which was on par with dual inoculation with Azospirillum and fluorescent pseudomonas (B_7) recorded the highest relative leaf water content and per cent increase over control was 185.58 and 73.47, respectively. The lowest relative leaf water content was recorded for dual inoculation with Azospirillum and phosphorus solubilising bacteria (B_5).

The effect of bioinoculants on relative growth rate was not consistant at second and third month after planting. Combined inoculation with Azospirillum, phosphorus solubilising bacteria and arbuscular mycorrhizal fungi (B_8) followed by uninoculated control (B_{10}) at second month after planting and uninoculated control (B_{10}) followed by phosphorus solubilising bacteria and arbuscular mycorrhizal fungi (B_8) at third month after planting were found beneficial in improving relative growth rate.

4.1.5 Performance of planting materials in nursery

The performance of vetiver saplings in relation to root growth potential, sturdiness quotient and sapling growth potential at first, second and third month after planting as influenced by single, dual, and combined application of bioinoculants in nursery are furnished in Table 10.

Root growth potential, sturdiness quotient and sapling growth potential of vetiver saplings were significantly influenced by treatment effects at all stages of growth. With respect to root growth potential, the effect of dual inoculation with Azospirillum and fluorescent pseudomonas (B_7) was pronounced throughout nursery period and the per cent increase over control was 172.5, 68.51 and 67.99 respectively at first, second and third month after planting.

Table 10. Quality attributes of vetiver saplings at 1, 2 and 3 MAP as influenced by single, dual and combined application of bioinoculants in nursery

Treat-ments	Root Growth Potential			Sturdiness Quotient			Sapling Growth Potential		
	1 MAP	2 MAP	3 MAP	1 MAP	2 MAP	3 MAP	1 MAP	2MAP	3MAP
B_1	2.46	2.34	2.57	73.97	134.97	189	0.054	0.065	0.078
B_2	2.55	3.05	3.09	95.1	140.17	192.23	0.061	0.075	0.088
B_3	4.31	3.67	3.49	85.3	92.9	117.9	0.026	0.054	0.069
B_4	2.29	2.26	2.43	89.93	102.43	163.9	0.029	0.056	0.056
B_5	2.03	2.36	2.62	83.13	119.1	172.7	0.019	0.021	0.034
B_6	2.97	3.13	2.86	90.97	120.17	163.73	0.039	0.059	0.066
B_7	7.48	4.81	4.31	90.08	112.7	170.17	0.028	0.049	0.062
B_8	3.84	3.77	3.73	72.27	117.1	174.17	0.034	0.051	0.066
B_9	3.49	3.04	3.20	86.27	138.1	183.1	0.042	0.057	0.071
B_{10}	2.55	2.86	2.57	96.93	100.9	158.33	0.022	0.050	0.069
CV (%)	46.19	24.59	19.34	9.12	13.32	12.01	37.89	24.30	21.49
SE	0.12	0.068	0.061	0.095	0.08	0.10	0.0024	0.0029	0.0029
CD (0.05)	0.451	0.247	0.223	0.345	0.292	0.369	0.005	0.006	0.006

RGP = Root length (cm) / Number of roots, SQ = Plant height (cm) / Collar girth (cm) or Tiller number

Sapling Growth Potential = Total dry matter production / (SQ + Shoot: Root ratio)

Sturdiness quotient also improved consequent to inoculation with phosphorus solubilising bacteria when estimated at two and three months after planting. Compared to control per cent increases were 38.92 percent and 21.41, respectively at second and third month after planting.

The impact of inoculation was remarkable with respect to sapling growth potential as well. Compared to control, single inoculation with phosphorus solubilising bacteria (B_1) significantly enhanced sapling growth potential to the tune of 177.27 per cent, 50 per cent and 27.54 per cent at first, second and third month after planting, respectively. However, when phosphorus solubilising bacteria was combined with Azospirillum there was considerable reduction in sapling growth potential especially at second and third month after planting.

4.1.6 Rhizosphere micro flora

The effect of nursery inoculation on mean population of Azospirillum, phosphorus solubilising bacteria, arbuscular mycorrhizal fungi and fluorescent pseudomonas at three months after planting are presented in Table 11.

Dual inoculation with Azospirillum and phosphorus solubilising bacteria (B_7) followed by combined inoculation with Azospirillum, phosphorus solubilising bacteria, arbuscular mycorrhizal fungi and fluorescent pseudomonas (B_9) significantly enhanced Azospirillum population at three months after planting. Population increased to the tune of 231.03 per cent over uninoculated control.

Single inoculation with phosphorus solubilising bacteria significantly enhanced the population of rhizosphere phosphorus solubilising bacteria to the extent of 236.36 percent over uninoculated control which registered the lowest population. Single inoculation with fluorescent pseudomonas was found favourable in significantly improving its population at three month after planting and compared to control the increase was 463.64 per cent.

Table 11. Microbial population of vetiver rhizosphere as influenced by single, dual and combined application of bio inoculants in nursery

Treatments	Azospirillum (No. of PopulationX 10-5 dilution CFU/g of soil)	Phosphorus Solubilizing Bacteria	AM Fungi Spores/100g soil	Fluorescent Pseudomonas
B_1	92	28	12	23
B_2	37	74	13	22
B_3	30	27	21	21
B_4	34	26	11	62
B_5	89	70	10	19
B_6	92	25	20	22
B_7	96	25	11	60
B_8	92	63	19	18
B_9	96	64	21	49
B_{10}	29	22	6	11
CV (%)	44.02	50.39	37.18	59.13
SE	0.94	0.94	0.75	0.84
CD (0.05)	3.41	3.38	2.69	3.05

MAP – Months After Planting

4.2.1 Morphological characters

Mean data on morphological characters namely plant height, leaf number and tiller production recorded at four, eight and twelve months after planting are presented in Table 12.

Row zone management and inter row zone management practices and their interactions didn't significantly influence plant height at four, eight and twelve months after planting. However, T_2 (*in situ* composting in trenches + stubble mulching - 122.33 cm) and B_3 (Mono cropping – 122.38 cm) resulted in taller plants at 12 months after planting. Interaction effects indicated the importance of T_2B_3 (*in situ* composting in trenches + stubble mulching and mono cropping – 127cm) in improving plant height.

Between the two control treatments, sole cropping at normal row planting (264.6 cm) significantly increased plant height at twelve months after planting. The effect of treatment combinations including controls was remarkable at eight and twelve month after planting. S_1 (normal row planting) which was on par with S_2 (paired row planting) at eight months after planting and S_1 (normal row planting) at 12 months after planting showed significant and positive influence on plant height.

The significant effect of row zone management practices on leaf number was evident only at four months after planting. T_3 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE – 753.83) which was on par with T_2 (*in situ* composting in trenches + stubble mulching – 693.67) registered the highest leaf number at four month after planting. Though not, significant T_3 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE) resulted in highest leaf number at eight month after planting. Inter row zone management practices had no appreciable effect on leaf number at any of the growth stages.

Table 12. Effect of row zone and inter-row zone management practices and their interactions on height, tiller production and leaf number of vetiver planted in trenches at 4, 8 and 12 MAP

Treat-ments	Plant height (cm)			Leaf number			Tiller production		
	4 MAP	8 MAP	12 MAP	4 MAP	8 MAP	12 MAP	4 MAP	8 MAP	12 MAP
Row zone management									
T_1	186.77	168.85	118.50	137.67	404.67	615.83	13.17	29.67	40.33
T_2	198.33	178.38	122.33	162.17	469.67	693.67	15.33	37.00	57.17
T_3	211.57	182.93	117.50	169.67	457.83	753.83	16.00	38.83	53.50
T_4	186.10	164.95	117.83	131.50	321.50	554.00	13.00	29.67	48.67
Inter-row zone management									
B_1	205.01	182.10	116.13	162.50	414.63	761.00	15.38	34.88	55.13
B_2	196.68	171.91	118.63	143.50	413.00	531.88	13.88	33.13	48.38
B_3	185.39	167.33	122.38	144.75	412.63	670.13	13.88	33.38	46.25
Interaction effects									
T_1B_1	183.05	166.00	124.00	133.50	278.50	494.50	12.50	24.00	37.00
T_1B_2	179.75	161.00	108.00	119.50	343.50	494.00	12.00	27.00	37.50
T_1B_3	197.50	179.55	123.50	160.00	592.00	859.00	15.00	38.00	46.50
T_2B_1	199.00	180.45	113.50	186.50	478.00	694.50	17.50	40.50	65.50
T_2B_2	201.15	177.55	126.50	146.00	424.00	515.00	14.00	33.50	50.50
T_2B_3	194.85	177.15	127.00	154.00	507.00	871.50	14.50	37.00	55.50
T_3B_1	239.10	203.55	108.50	179.00	419.50	1014.00	16.50	37.00	55.50
T_3B_2	219.25	186.25	118.50	185.50	630.00	679.50	17.50	44.00	58.00
T_3B_3	176.35	159.00	125.50	144.50	324.00	568.00	14.00	35.50	47.00

T_4B_1	198.90	178.40	118.50	151.00	482.50	841.00	15.00	38.00	62.50
T_4B_2	186.55	162.85	121.50	123.00	254.50	439.00	12.00	28.00	47.50
T_4B_3	172.85	153.60	113.50	120.50	227.50	382.00	12.00	23.00	36.00
Treatment mean	195.69	173.78	119.04	150.25	413.42	654.33	14.38	33.79	49.917
Controls									
NRP	245.9	264.6	288	149	279.5	423.5	14	30.5	49
PRP	204	231.9	254.5	106.5	221.5	411	10	19.5	41.5
Control mean	224.95	248.25	271.25	127.75	250.5	417.25	12	25	45.25
SE									
T	11.94	10.06	7.39	13.34	92.98	111.91	1.45	5.28	7.093
B	10.34	8.70	6.40	11.55	80.52	96.91	1.26	4.57	6.14
TB	20.68	17.42	12.80	23.09	161.04	193.83	2.51	9.15	12.29
CD (0.05)									
T	NS	NS	NS	28.81	NS	NS	NS	NS	NS
B	NS	NS	NS	NS	NS	NS	NS	NS	NS
TB	NS	NS	NS	NS	NS	NS	NS	NS	NS
Treatments *Vs* Control	24.13	20.32	14.94	NS	NS	226.15	NS	NS	NS
Between controls	NS	NS	7.98	NS	NS	NS	NS	NS	NS
Between treatments (including controls)	NS	37.63	27.66	NS	NS	NS	NS	NS	NS

NS – Not significant MAP – Months After Planting

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However, B_1 (multiple cropping -761) in broad beds improved leaf number. Though interaction effects was significant at all growth stages T_3B_2 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE and double cropping – 679.50) and T_3B_1 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE and multiple cropping – 1014.00) enhanced leaf number at eight and twelve month after planting. Method of planting in sole cropping was insignificant in influencing leaf number though S_1 (normal row planting) produce more number of leaves compared to paired row planting pattern.

The effect of treatment combinations including control was insignificant in influencing leaf number at any of the growth stages. However, integration of insitu composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE and multiple cropping in broad beds enhanced leaf number at harvest.

Row zone management practices, inter row zone management practices and their interactions didn't exert any significant influence on tiller production at any of the growth stages. However, T_2 (*in situ* composting in trenches + stubble mulching-57.17), recorded highest tiller production at twelve months after planting. B_1 (multiple cropping) was beneficial in increasing tiller production throughout crop growth. Integration of above two factors, *ie*, T2B1 (*in situ* composting in trenches + stubble mulching and multiple cropping) registered the highest tiller count of 65.5. Between the two controls normal row planting enhanced tiller production compared to paired row planting. Interaction effects of treatment combinations including controls also influenced tiller production.

4.2.2 Root parameters

Effect of row zone and inter row zone management practices and their interactions on root parameters of vetiver; namely length, number, spread and weight of roots recorded at four, eight, twelve months after planting are depicted in Table 13.

The effect of row zone management was significant in influencing root number at all stages of crop growth and T_3 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE) which was on par with T_2 (*in situ* composting in trenches + Stubble mulching) registered greater values of 666.33 and 827.83 at four, eight, and twelve months after planting, respectively. At twelve months after planting T_2 (*in situ* composting in trenches + stubble mulching) which was on par with T_1 (*in situ* composting in trenches) and T_3 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE) recorded the highest root number. Inter row zone management had no significant effect on root number. However, multiple cropping enhanced root number at twelve months after planting.

Interaction effects of above two factors were also insignificant in influencing root number. However, T_3B_2 (*in situ* composting in trenches+ Stubble mulching + summer irrigation at 40 mm CPE and double cropping) at four and eight month after planting, T_2B_1(*in situ* composting in trenches + stubble mulching and multiple cropping-914.5) at twelve month after planting produced greater number of roots. Between the two controls, paired row planting pattern promoted root number production compared to normal row planting at all stages of growth.

The interaction effects of treatments including controls significantly influence root number at four and twelve month after planting and the treatment combination T_3B_2 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE and double cropping) at four months after planting and T_2B_1(*in situ* composting in trenches + stubble mulching and multiple cropping) at twelve months after planting recorded greater root number and per cent increase in root number was 212.27 and 197.40 over sole cropping at normal row planting respectively.

Table 13.Effect of row zone and inter-row zone management practices and their interactions on root parameters of vetiver planted in trenches at 4, 8 and 12 MAP

Treatments	Root number			Root length (cm)			Root spread (cm)			Root weight (g/plant)		
	4 MAP	8 MAP	12 MAP	4 MAP	8 MAP	12 MAP	4 MAP	8 MAP	12 MAP	4 MAP	8 MAP	12 MAP
Row zone management												
T_1	271.33	381.67	729.17	30.35	46.85	61.62	18.37	26.43	30.67	77.33	105.33	157.83
T_2	300.00	439.67	827.83	27.87	41.65	64.97	18.22	25.82	29.23	62.67	117.33	174.17
T_3	359.17	549.50	666.33	30.08	45.00	55.80	18.78	27.28	31.27	77.33	115.00	174.50
T_4	211.83	307.50	462.67	28.13	42.03	50.70	16.77	24.23	27.02	64.00	114.17	193.83
Inter-row zone management												
B_1	285.88	393.63	751.25	31.41	48.75	60.34	16.66	25.63	27.90	78.25	119.75	197.88
B_2	299.13	457.75	602.25	26.96	39.90	56.80	20.54	27.29	31.53	63.125	108.63	184.13
B_3	271.75	407.38	661.00	28.95	43.00	57.68	16.90	24.91	29.21	69.625	110.5	143.25
Interaction effects												
T_1B_1	254.50	336.50	719.00	33.10	57.55	65.90	14.10	23.45	27.25	93.50	110.00	188.00
T_1B_2	251.50	355.50	653.50	28.15	39.50	61.35	15.85	24.30	30.90	67.00	101.00	163.50
T_1B_3	308.00	453.00	815.00	29.80	43.50	57.60	25.15	31.55	33.85	71.50	105.00	122.00
T_2B_1	273.00	403.00	914.50	27.90	42.45	68.75	14.20	23.10	24.45	57.00	124.50	198.00
T_2B_2	329.00	469.00	729.00	26.15	37.50	62.85	26.80	32.45	34.35	77.00	109.00	193.50
T_2B_3	298.00	447.00	840.00	29.55	45.00	63.30	13.65	21.90	28.90	54.00	118.50	131.00
T_3B_1	314.50	412.00	622.50	30.25	45.00	48.85	20.45	28.65	31.30	89.50	130.50	200.00
T_3B_2	420.00	721.00	699.00	28.65	43.00	55.50	20.45	28.30	31.75	59.50	103.50	177.50
T_3B_3	343.00	515.50	677.50	31.35	47.00	63.05	15.45	24.90	30.75	83.00	111.00	146.00

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T_4B_1	301.50	423.00	749.00	34.40	50.00	57.85	17.90	27.30	28.60	73.00	114.00	205.50
T_4B_2	196.00	285.50	327.50	24.90	39.60	47.50	19.05	24.10	29.10	49.00	121.00	202.00
T_4B_3	138.00	214.00	311.50	25.10	36.50	46.75	13.35	21.30	23.35	70.00	107.50	174.00
Treatment mean	285.58	419.58	671.5	29.108	43.88	58.27	18.03	25.94	29.55	70.33	112.96	175.08
Controls												
NRP	134.5	245.5	307.5	24.75	39.8	48.5	14.2	23	24.05	47.5	73.5	99.5
PRP	154	276.5	311	25	40.8	51	16.3	25.65	27.15	48.5	78.5	101
Control mean	144.25	261	309.25	24.88	40.3	49.75	15.25	24.33	25.6	48	76	100.25
SE												
T	39.67	75.04	107.05	1.97	3.84	4.52	2.40	2.14	1.63	2.91	3.63	4.01
B	34.35	64.99	92.71	1.71	3.33	3.92	2.09	1.85	1.41	2.52	3.14	3.48
TB	68.71	129.97	185.41	3.41	6.65	7.83	4.17	3.69	2.83	5.034	6.29	6.95
CD (0.05)												
T	85.69	162.11	231.26	NS	NS	9.77	NS	NS	NS	6.28	7.84	8.67
B	NS	NS	NS	NS	NS	NS	NS	NS	NS	5.44	6.79	7.51
TB	NS	NS	NS	NS	NS	NS	9.01	7.99	NS	10.88	13.58	15.02
Treatments *Vs* Control	80.16	151.64	216.33	3.99	NS	NS	NS	NS	3.30	5.87	7.33	8.11
Between controls	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Between treatments (including controls)	148.43	NS	400.56	NS	NS	NS	NS	NS	6.11	10.88	13.58	15.02

NS – Not significant

MAP – Months After Planting

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Row zone management practices significantly influenced root length at twelve months after planting and T_2 (*in situ* composting in trenches + stubble mulching) which was on par with T_1 (*in situ* composting in trenches) and T_3 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE) produced longer roots. Though inter row zone management practices had no significant influence on root length B_1 (multiple cropping) showed greater length of roots throughout the growth period. Similar to main effects, interaction effects were also insignificant in influencing root length at different stages of crop growth. However, T_2B_1 (*in situ* composting in trenches + Stubble mulching and multiple cropping-68.75) recorded greater root length at twelve month after planting. A similar trend was observed between treatments including controls. Between the two control treatments, paired row planting pattern produced longer roots compared to normal row planted vetiver.

The influence of row zone and inter row zone management practices were insignificant in influencing root spread. However, T_3 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE -31.27 cm) and B_2 (double cropping – 31.53) registered greater spread of root. Integration of row zone and inter row zone management practices had appreciable effect on root spread at four and eight month after planting and T_2B_2 (*in situ* composting in trenches + stubble mulching and double cropping) recorded greater values at both stages of growth. However, the interaction effect was insignificant at twelve months after planting. Though, not significant paired row planting pattern resulted in greater spread of roots compared to normal row planting at all stages of growth.

Between treatments including control the effect was significant at harvest and similar to interaction effects between treatments, integration of T_2B_2 (*in situ* composting in trenches + stubble mulching and double cropping – 34.35) resulted in greater spread of roots.

Row zone management practices significantly influenced root weight at all stages of crop growth. T_1 (*in situ* composting in trenches) on par with T_3 (*in situ* composting in trenches+ Stubble mulching + summer irrigation at 40 mm CPE), T_2 (*in situ* composting in trenches + stubble mulching) on par with T_3 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE) and T_4 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 80 mm CPE) recorded significantly higher values at four, eight, and twelve months after planting, respectively. The effect of inter row zone management was spectacular in influencing root weight and multiple cropping significantly enhanced this parameter at all stages of growth.

Interaction effects of the above two factors had positive and favourable influence on root weight. T_1B_1 (*in situ* composting in trenches and multiple cropping) on par with T_3B_1 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE and multiple cropping) and T_3B_3(*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE and mono cropping); T_3B_1(*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE and multiple cropping) on par with T_2B_1(*in situ* composting in trenches + Stubble mulching and multiple cropping), T_4B_2(*in situ* composting in trenches+ stubble mulching + summer irrigation at 80 mm CPE and double cropping), and T_2B_3 (*in situ* composting in trenches + stubble mulching and mono cropping) ; T_4B_1(*in situ* composting in trenches+ stubble mulching + summer irrigation at 80 mm CPE and multiple cropping) on par with T_4B_2 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 80 mm CPE and double cropping), T_3B_1 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE and multiple cropping), T_2B_1 (*in situ* composting in trenches + stubble mulching and multiple cropping), and T_2B_2 (*in situ* composting in trenches + stubble mulching and double cropping) registered higher values at four, eight, and twelve month after planting respectively. Almost a similar trend was observed between treatments including controls. The effect of planting pattern was found insignificant in influencing root yield. However, paired row planting pattern was found favourable for improving root yield over normal row planting.

4.2.3 Physiological and bio chemical parameters

Data on relative leaf water content and chlorophyll content as influenced by the effect of row zone and inter row zone management practices and their interactions are furnished in Tables 14 and 15.

The effect of row zone management practices was evident at eight and twelve month after planting and T_3 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE) on par with T_2 and T_4; and T_2 (*in situ* composting in trenches + stubble mulching) were beneficial in enhancing relative leaf water content at eight and twelve month after planting respectively.

The significance of inter row zone management practices was observed at twelve months after planting alone and B_3 (mono cropping) was found to enhance relative leaf water content.

Interaction effect was significant at twelve months after planting alone and T_2B_1 (insitu composting in trenches + Stubble mulching and multiple cropping) which was on par with T_2B_3, T_2B_2 and T_4B_1 registered higher relative leaf water content (94.2). Relative leaf water content was not at all significantly influenced by planting patterns. However, paired row planting patterns improved relative leaf water content at eight and twelve months after planting. Between treatments including controls the effects of interaction of T_3B_2 (*in situ* composting in trenches+ Stubble mulching + summer irrigation at 40 mm CPE and double cropping) at eight months after planting and T_2B_1(in situ composting in trenches + Stubble mulching and multiple cropping) at twelve months after planting were conspicuous for improving relative leaf water content.

Table 14. Effect of row zone and inter-row zone management and their interactions on physiological parameters of vetiver planted in trenches at 4, 8 and 12 MAP

Treatments	Relative leaf water content (%)			Leaf dry matter (g)			Root dry matter (g)			Total dry matter (g/plant)		
	4 MAP	8 MAP	12 MAP	4 MAP	8 MAP	12 MAP	4 MAP	8 MAP	12 MAP	4 MAP	8 MAP	12 MAP
Row zone management												
T_1	88.25	79.63	77.28	195.06	147.10	125.75	77.33	105.33	157.83	272.39	252.44	283.58
T_2	90.03	91.60	92.87	165.14	214.95	153.19	62.67	117.33	174.17	227.81	332.28	327.36
T_3	90.72	92.10	84.05	166.70	207.62	149.41	77.33	115.00	174.50	244.03	322.62	323.90
T_4	87.97	89.35	83.58	182.42	196.64	171.36	64.00	114.17	193.83	246.42	310.81	365.19
Inter-row zone management												
B_1	89.95	89.20	84.29	200.11	196.78	167.16	78.25	119.75	197.88	278.36	316.53	365.04
B_2	88.93	87.74	82.04	162.79	174.62	152.45	63.13	108.63	184.13	225.91	283.24	336.58
B_3	88.85	87.58	87.01	169.09	203.34	130.17	69.63	110.5	143.25	238.72	313.84	273.42
Interaction effects												
T_1B_1	87.25	79.85	77.15	223.37	144.58	152.19	93.50	110.00	188.00	316.87	254.58	340.19
T_1B_2	87.00	77.55	74.95	169.05	140.41	122.26	67.00	101.00	163.50	236.05	241.41	285.76
T_1B_3	90.50	81.50	79.75	192.75	156.32	102.78	71.50	105.00	122.00	264.25	261.32	224.78
T_2B_1	91.40	93.45	94.20	165.65	215.47	152.08	57.00	124.50	198.00	222.65	339.97	350.08
T_2B_2	89.25	90.35	91.90	167.63	204.59	162.09	77.00	109.00	193.50	244.63	313.59	355.59
T_2B_3	89.45	91.00	92.50	162.15	224.79	145.40	54.00	118.50	131.00	216.15	343.29	276.40
T_3B_1	91.20	92.50	75.75	231.57	228.94	179.62	89.50	130.50	200.00	321.07	359.44	379.62
T_3B_2	92.40	93.90	87.35	143.63	181.63	123.70	59.50	103.50	177.50	203.13	285.13	301.20
T_3B_3	88.55	89.90	89.05	124.89	212.28	144.89	83.00	111.00	146.00	207.89	323.28	290.89

T_4B_1	89.95	91.00	90.05	179.83	198.13	184.76	73.00	114.00	205.50	252.83	312.13	390.26
T_4B_2	87.05	89.15	73.95	170.84	171.83	201.75	49.00	121.00	202.00	219.84	292.83	403.75
T_4B_3	86.90	87.90	86.75	196.58	219.97	127.59	70.00	107.50	174.00	266.58	327.47	301.59
Treatment mean	89.24	88.17	84.45	177.33	191.58	149.93	70.33	112.96	175.08	247.66	304.54	325.01
Controls												
NRP	88.3	79.2	79.5	152.59	149.98	94.95	47.5	73.5	99.5	200.09	223.48	194.45
PRP	85.55	81.2	81.65	148.49	136.02	99.15	48.5	78.5	101	196.99	214.55	200.15
Control mean	86.93	80.2	80.58	150.54	143	97.05	48	76	100.25	198.54	219.02	197.3
SE												
T	1.25	1.64	1.18	11.14	8.48	6.66	2.91	3.63	4.01	11.97	9.80	8.24
B	1.08	1.42	1.02	9.65	7.34	5.76	2.52	3.14	3.48	10.37	8.49	7.14
TB	2.16	2.84	2.04	19.29	14.68	11.53	5.03	6.29	6.95	20.73	16.98	14.28
CD (0.05)												
T	NS	3.54	2.54	NS	18.31	14.38	6.28	7.84	8.67	25.86	21.18	17.81
B	NS	NS	2.20	20.84	15.86	12.45	5.44	6.79	7.51	22.39	18.34	15.42
TB	NS	NS	4.40	41.68	NS	24.91	10.88	13.58	15.02	44.79	NS	30.84
Treatments Vs Control	NS	3.31	2.38	22.51	17.13	13.45	5.87	7.33	8.11	24.19	19.81	16.66
Between controls	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Between treatments (including controls)	NS	6.13	4.40	41.68	31.72	24.91	10.87	13.58	15.02	44.79	36.68	30.84

NS – Not significant

MAP – Months After Planting

Row zone management practices significantly influenced leaf chlorophyll content at 12 months after planting alone and T_2 (*in situ* composting in trenches + Stubble mulching) on par with T_1 and T_3 registered higher values. Inter row zone management practices did not significantly influence chlorophyll content at any stage of growth.

Interaction effects influenced chlorophyll content only at twelve months after planting and T_2B_1 (*in situ* composting in trenches + Stubble mulching and multiple cropping) which was found be on par with T_3B_3, T_2B_2, T_1B_2, T_1B_1, T_2B_3, T_4B_2, T_4B_1, T_1B_3 and T_3B_1 recorded the highest value. Chlorophyll content was unaffected by planting patterns. Between treatments including control, the effect was appreciable at twelve months after planting alone and the treatment combination T_2B_1 (*in situ* composting in trenches + Stubble mulching and multiple cropping) on par with T_3B_3,T_2B_2, T_1B_2, T_1B_1, T_2B_3, T_4B_2,T_4B_1,T_1B_3 and T_3B_1 showed greater chlorophyll contents.

4.2.4 Dry matter production

The effect of row zone and inter row zone management practices and their interactions on leaf dry matter production, root dry matter production and total dry matter production estimated at four , eight and twelve month after planting are furnished in Table 14.

Leaf dry matter production was significantly influenced by row zone management practices. T_2 (*in situ* composting in trenches + Stubble mulching) on par with T_3 and T_4 at eight months after planting and T_4 (*in situ* composting in trenches+ Stubble mulching + summer irrigation at 80 mm CPE) at twelve month after planting produced higher leaf dry matter. Though inconsistent, the influence of inter row zone management practices was evident throughout crop growth. B_1 at four and twelve months after planting, B_3 at eight months after planting were found to be significantly superior in influencing leaf dry matter production. Interaction effects of above practices were remarkable at four and twelve months after planting, T_3B_1 at four months after planting and T_4B_2 at twelve months after planting recorded greater dry matter production. A similar trend was observed between treatments including control in respect of the above parameter. Planting patterns had no significant effect on leaf dry matter production.

Row zone and inter row zone management practices and their interactions significantly influenced root dry matter production at various stages of growth. T_1 on par with T_3 at four months after planting, T_2 on par with T_3 and T_4 at eight months after planting and T_4 at twelve months after planting registered significantly higher root dry matter production. In general the effect of inter row zone management practices was consistent throughout crop growth and B_1 at all stages recorded significantly higher root dry matter production. Integration of row zone and inter row zone management practices also revealed the significant impact of T_1B_1 on par with T_3B_1 and T_3B_3; T_3B_1 on par with T_2B_1, T_4B_2 and T_2B_3; and T_4B_1 on par with T_4B_2, T_3B_1,T_2B_1 and T_2B_2 in increasing root dry matter production at four, eight and twelve months after planting respectively. The trend was almost similar between treatments including control with respect to this parameter. At four, eight and twelve months after planting, the increase in root dry matter production in T_1B_1,T_3B_1, and T_4B_1 were 96.84 percent,77.55 percent, and 101.01 percent respectively over the control (normal row planting). No significant variation was observed between controls with respect to root dry matter production.

Total dry matter production was also found to be significantly influenced by the main effects and interaction effects of different treatments at all stages of growth. In general T_1, T_2 and T_4 recorded significantly greater total dry matter production at four, eight and twelve months after planting, respectively. Effect of B_1 was significant at all stages of growth. Treatment combinations also exerted significant effect on total dry matter production and T_3B_1 on par with T_1B_1 at four months after planting and T_4B_2 on par with T_4B_1 and T_3B_1 at twelve months after planting were beneficial for enhancing total dry matter production. Comparison between treatments including control revealed that T_3B_1 on par with T_1B_1; T_3B_1 on par with T_2B_3, T_2B_1, T_4B_3 and T_3B_3; and T_4B_2 on par with T_4B_1 and T_3B_1 registered significantly greater total dry matter production. Compared to control (normal row planting) increase in total dry matter production in T_4B_2 was 107.64 percent. Though not significant, paired row planting registered greater dry matter production at twelve months after planting over the control (normal row planting) and the increase was 2.93 percent.

4.2.5 Dry matter partitioning

Partitioning of dry matter into leaf and root as influenced by row zone and inter row zone management practices and their interactions estimated at four, eight and twelve months after planting are depicted in Table 15.

Row zone management practices significantly influenced dry matter partitioning only at four, and eight months after planting. At four months after planting, highest per cent of dry matter partitioning in favour of leaf was observed in T_4 which was on par with T_2 and T_1. At eight months after planting, T_2 on par with T_3 and T_4 registered the highest per cent of dry matter partitioning in favour of leaf. Inter row zone management practices influenced dry matter partitioning only at eight and twelve months after planting and B_3 at both stages recorded significantly higher percent of partitioning in favour of leaf. Interaction effects also indicated the significance of T_4B_2 on par with T_2B_3, T_2B_1, T_4B_3 and T_1B_3 at four months after planting; and T_2B_3 on par with T_4B_2 and T_3B_3 at twelve months after planting in partitioning of dry matter in favour of leaves.

The trend was almost similar between treatments including control. However, planting patterns didn't significantly influenced dry matter partitioning in favour of leaves.

Table 15. Effect of row zone and inter-row zone management and their interactions on partitioning of dry matter (%) and chlorophyll content of vetiver planted in trenches at 4, 8 and 12 MAP

Treatments	Dry matter – 4 MAP		Dry matter – 8 MAP		Dry matter – 12 MAP		Chlorophyll		
	Leaf (%)	Root (%)	Leaf (%)	Root (%)	Leaf (%)	Root (%)	4 MAP	8 MAP	12 MAP
Row zone management									
T_1	71.62	28.38	58.28	41.72	44.41	55.59	38.88	36.07	34.52
T_2	72.59	27.41	64.67	35.33	47.20	52.80	36.22	38.73	36.02
T_3	67.61	32.39	64.35	35.65	46.06	53.94	36.87	38.22	32.78
T_4	74.08	25.92	62.92	37.08	46.47	53.53	35.02	37.22	30.27
Inter-row zone management									
B_1	71.96	28.04	61.74	38.26	45.67	54.34	35.19	36.03	34.59
B_2	72.08	27.92	61.40	38.59	44.84	55.17	39.35	39.75	33.91
B_3	70.39	29.61	64.53	35.47	47.6	52.4	35.70	36.90	31.69
Interaction effects									
T_1B_1	70.43	29.57	56.82	43.18	44.76	55.24	41.35	36.75	35.10
T_1B_2	71.63	28.37	58.15	41.85	42.79	57.21	41.05	37.95	35.80
T_1B_3	72.79	27.21	59.86	40.14	45.67	54.33	34.25	33.50	32.65
T_2B_1	74.40	25.60	63.38	36.62	43.41	56.59	30.40	34.95	37.95
T_2B_2	68.36	31.64	65.17	34.83	45.57	54.43	39.35	40.85	36.25
T_2B_3	75.01	24.99	65.47	34.53	52.61	47.39	38.90	40.40	33.85
T_3B_1	72.06	27.94	63.68	36.32	47.30	52.70	34.95	36.40	32.20
T_3B_2	70.72	29.28	63.70	36.30	41.08	58.92	36.15	37.10	29.75
T_3B_3	60.05	39.95	65.67	34.33	49.81	50.19	39.50	41.15	36.40
T_4B_1	70.93	29.07	63.07	36.93	47.19	52.81	34.05	36.00	33.10

T_4B_2	77.59	22.41	58.59	41.41	49.90	50.10	40.85	43.10	33.85
T_4B_3	73.72	26.28	67.12	32.88	42.31	57.69	30.15	32.55	23.85
Treatment mean	71.47	28.53	62.56	37.44	46.03	53.97	36.75	37.56	33.39
Controls									
NRP	76.21	33.02	66.98	33.02	48.78	51.22	34.9	33.1	30.8
PRP	75.36	36.62	63.38	36.62	49.52	50.48	34.3	32.9	31.05
Control mean	75.79	34.82	65.18	34.82	49.15	50.85	34.6	33	30.93
SE									
T	1.28	1.28	1.22	1.22	1.12	1.12	2.25	2.06	1.59
B	1.11	1.11	1.06	1.06	0.97	0.97	1.94	1.78	1.37
TB	2.22	2.22	2.12	2.12	1.94	1.94	3.89	3.56	2.75
CD (0.05)									
T	2.77	2.77	2.64	2.64	NS	NS	NS	NS	3.43
B	NS	NS	2.29	2.29	2.09	2.09	NS	NS	NS
TB	4.80	4.80	NS	NS	4.18	4.18	NS	NS	5.93
Treatments Vs Control	2.59	2.59	2.47	2.47	2.26	2.26	NS	4.15	NS
Between controls	NS	NS	NS	NS	NS	NS	NS	NS	NS
Between treatments (including controls)	4.80	4.80	4.58	4.58	4.18	4.18	NS	NS	5.93

NS – Not significant MAP – Months After Planting

Similar to leaf dry matter, row zone management practices significantly influenced root dry matter per cent only at four and eight months after planting. T_3 and T_1 recorded positive and significant influence in partitioning of dry matter for improving root yield. Like leaf dry matter per cent, root dry matter per cent was significantly influenced by inter row zone management practices only at eight and twelve months after planting and at both stages B_2 on par with B_1 recorded greater partitioning of dry matter in favour of roots. Interaction effects also influenced dry matter per cent at four and twelve months after planting, T_3B_3 at twelve months after planting and T_3B_2 on par with T_4B_3, T_1B_2, T_2B_1 and T_1B_1 significantly favoured dry matter partitioning in favour of roots. Similar to leaf dry matter per cent, root dry matter per cent was also found to be unaffected by planting patterns.

4.2.6 Soil moisture studies

Mean data on moisture percent of soil before and after irrigation, seasonal consumptive use, mean daily consumptive use, crop coefficient, crop water use efficiency, field water use efficiency and water productivity as influenced by row zone and inter row zone management practices and their interactions are furnished in Table 16.

Row zone management practices significantly influenced soil moisture content both before and after irrigation. Before irrigation, soil moisture ranged from 11.51% to 13.55%. T_4 recorded the highest moisture content both before and after irrigation followed by T_3. Soil moisture content before irrigation was also significantly influenced by inter row zone management practices and ranged from 11.76% to 12.91%. B_1 which was on par with B_2 registered the highest value of 9.78%. Treatment combinations didn't significantly influence moisture content before and after irrigation. Similarly planting patterns didn't exert any significant effect on soil moisture both before and after irrigation. Significant effect of treatment combinations including control was evident on soil moisture. Integration of T_4 and

B_2 before irrigation (14.25%) and T_4 and B_1 after irrigation (17.73%) retained higher moisture in the soil.

Seasonal consumptive use, mean daily consumptive use and crop coefficient were not at all influenced by row zone and inter row zone management practices and their interactions. Trend was similar with respect of planting pattern as well. With respect to treatment combinations including control seasonal consumptive use ranged from 498.81 to 698 mm and mean daily consumptive use from 1.37 to 1.91 mm and crop coefficient from 0.52 to 0.73. T_1B_1 depleted the highest amount of moisture (39.3, 38.6 per cent) in terms of seasonal consumptive use, mean daily consumptive use, where as T_2B_3 the highest crop coefficient value (0.73).

Crop water use efficiency, field water use efficiency and water productivity were remarkably influenced by row zone and inter row zone management practices and their interactions. T_4 registered highest crop water use efficiency and field water use efficiency of 1164.05 and 0.2368 g m^{-3} respectively whereas T_2 recorded higher water productivity (1300.18 g m^{-3}).

With respect to inter row zone management practices, B_1, was found significantly superior to all other treatments in enhancing crop water use efficiency, field water use efficiency and water productivity and the values were 1229.10, 0.243 and 1186.57 g m^{-3} respectively. Interaction effects of treatments including control significantly influenced water use efficiency and water productivity. Crop water use efficiency ranged from 301.83 to 1549.95 g m^{-3} and the highest value of 1549.95 g m^{-3} was achieved, when T_4 was integrated with B_1 and it was 413.52 per cent higher compared to normal row planting. Field water use efficiency ranged from 0.073 to 0.3 g m^{-3} and the above treatment combination recorded the highest use efficiency which was 310.96 per cent higher compared to normal row planting. Water productivity varied from 804.27 g m^{-3} to 1395.31 g m^{-3} and integration of T_2 and B_1 was found favourable for enhancing water productivity to the tune of 1395.31 and it was 73.49 g m^{-3}.

Table 16. Soil moisture studies as influenced by the effect of row zone and inter-row zone management and their interactions on vetiver

Treatments	Soil Moisture (%)		Seasonal Cu (mm)	Mean Daily Cu (mm)	Kc	CWUE (g m-3)	FWUE (g m-3)	Water Productivity (g m-3)
	Before	After						
Row zone management								
T_1	11.51	15.17	611.25	1.67	0.61	882.08	0.19	1101.51
T_2	11.60	15.67	545.52	1.49	0.67	1112.02	0.21	1300.18
T_3	12.86	16.72	573.06	1.57	0.64	1013.62	0.14	997.72
T_4	13.55	17.47	638.61	1.75	0.59	1164.05	0.24	987.21
Inter-row zone management								
B_1	12.91	16.50	618.09	1.69	0.60	1229.10	0.24	1186.57
B_2	12.48	16.22	592.27	1.62	0.62	1046.74	0.19	1097.33
B_3	11.76	16.06	565.96	1.55	0.67	852.99	0.15	1006.07
Interaction effects								
T_1B_1	12.19	15.34	698.00	1.91	0.52	928.51	0.23	1168.13
T_1B_2	11.16	15.09	564.78	1.55	0.65	924.60	0.18	1116.79
T_1B_3	11.20	15.09	570.96	1.56	0.65	793.13	0.16	1019.61
T_2B_1	11.76	15.69	561.52	1.54	0.65	1344.43	0.27	1395.31
T_2B_2	11.81	15.66	576.22	1.58	0.64	1059.87	0.21	1254.98
T_2B_3	11.24	15.66	498.81	1.37	0.73	931.77	0.16	1250.26
T_3B_1	13.72	17.23	627.38	1.72	0.58	1093.52	0.17	1070.69
T_3B_2	12.70	16.54	572.07	1.57	0.64	1041.55	0.15	997.24
T_3B_3	12.16	16.39	519.74	1.42	0.70	905.80	0.12	925.24
T_4B_1	13.96	17.73	585.45	1.60	0.62	1549.95	0.30	1112.16
T_4B_2	14.25	17.61	656.03	1.80	0.56	1160.92	0.25	1020.30

T_4B_3	12.44	17.09	674.34	1.85	0.59	781.27	0.16	829.18
Treatment mean	12.38	16.26	592.11	1.62	0.63	1042.94	0.19	1096.66
Controls								
NRP	11.55	14.75	688.04	1.89	0.53	301.83	0.07	804.27
PRP	11.22	14.96	608.05	1.67	0.62	413.62	0.09	829.17
Control mean	11.38	14.86	648.05	1.78	0.58	357.73	0.079	816.72
SE								
T	0.37	0.41	54.83	0.15	0.05	70.85	0.008	31.89
B	0.32	0.37	47.49	0.13	0.046	61.35	0.007	27.63
TB	0.64	0.73	94.98	0.26	0.09	122.71	0.014	55.25
CD (0.05)								
T	0.79	0.91	NS	NS	NS	153.05	0.018	68.91
B	0.69	NS	NS	NS	NS	132.55	0.015	59.68
TB	NS	NS	NS	NS	NS	265.09	0.031	NS
Treatments Vs Control	0.74	0.86	NS	NS	NS	143.17	0.017	64.46
Between controls	NS	NS	NS	NS	NS	NS	NS	NS
Between treatments (including controls)	1.38	1.58	NS	NS	NS	265.09	0.030	119.36

NS – Not significant MAP – Months After Planting

4.2.7 Root yield

The effect of row zone and inter row zone management practices and their interactions on row zone root yield at twelve month after planting and cumulative root yield per unit area are depicted in Table 17.

Spectacular effect of row zone management practices was observed on row zone root production of vetiver planted in trenches. The main effect of T_4 (*in situ composting in trenches+ stubble mulching + summer irrigation at 80 mm* CPE) was found superior and it differed significantly from all other treatments. Compared to T_1 which recorded the lowest yield, the percent increase in root production was 39.78. Similarly, inter row zone management practices also significantly influenced row zone root production and B_1 (multiple cropping) registered highest yield (1258.88 g/plot) followed by B_2 and B_3.

Interaction effects were also found remarkable and integration of T_4 (*in situ* composting in trenches+ Stubble mulching + summer irrigation at 80 mm CPE) and B_1 (multiple cropping) recorded the highest root yield and differed significantly from all other treatment combinations. A similar trend was observed between treatments including controls. The treatment combination, T_4B_1 (*in situ* composting in trenches+ Stubble mulching + summer irrigation at 80 mm CPE and multiple cropping) which was significantly different from all other combinations registered the highest root yield and the per cent increase over control (normal row planting) was 185.06. T_4B_1 was followed by T_4B_2 and T_2B_1.

Spectacular improvements in cumulative root yield per unit area was observed due to main and interaction effects of row zone and inter row zone management practices.

Significant improvement in root productivity was observed in T_4 *(in situ* composting in trenches+ stubble mulching + summer irrigation at 80 mm CPE) compared to all other levels.

Table 17. Effect of row zone and inter-row zone management practices and their interactions on row zone root yield at 12 MAP and cumulative root yield per unit area

Treatments	Row zone (g/plot)	Grand total (Row zone +inter row zone) Cumulative root yield per unit area	
	12 MAP	(g/plot)	(t/ha)
Row zone management			
T_1	929.67	1478.17	3.69
T_2	1070.83	1661.33	4.15
T_3	978.67	1599.57	3.99
T_4	1299.50	1970.57	4.93
Inter-row zone management			
B_1	1258.88	2049.73	5.13
B_2	1055	1697.88	4.25
B_3	895.13	1284.63	3.21
Interaction effects			
T_1B_1	1021.50	1772.00	4.43
T_1B_2	896.00	1427.00	3.57
T_1B_3	871.50	1235.50	3.09
T_2B_1	1290.00	2067.00	5.17
T_2B_2	1042.00	1644.00	4.11
T_2B_3	880.50	1273.00	3.18
T_3B_1	1102.00	1875.30	4.69
T_3B_2	940.50	1633.90	4.08
T_3B_3	893.50	1289.50	3.22

T_4B_1	1622.00	2484.60	6.21
T_4B_2	1341.50	2086.60	5.22
T_4B_3	935.00	1340.50	3.35
Treatment mean	1069.67	1677.41	4.19
Controls			
NRP	569	569	1.4225
PRP	659.5	659.5	1.64875
Control mean	614.25	614.25	1.535625
SE			
T	42.93	58.92	0.15
B	37.18	51.02	0.13
TB	74.36	102.05	0.26
CD (0.05)			
T	92.75	127.28	0.318
B	80.32	110.23	0.28
TB	160.64	220.46	0.55
Treatments Vs Control	86.76	119.06	0.29
Between controls	NS	NS	NS
Between treatments (including controls)	160.64	220.46	0.55

NS – Not significant MAP – Months After Planting

This was followed by T_2 and T_3 which were on par compared to T_1 which recorded *the lowest productivity. The per cent increase in* T_4 was 33.60.

The inter row zone management practices also recorded significant effect on cumulative root productivity and B_1 (multiple cropping) resulted in significant improvement which was followed by double cropping and mono cropping. The per cent increase in root productivity due to multiple cropping was 59.81 over mono cropping. Interaction of row zone and inter row zone management practices also significantly enhanced root productivity.

The treatment combination T_4B_1 which differed significantly from all other combinations registered the highest root productivity. The trend was similar between treatments including controls and the increase in root productivity was to the tune of 337.32 per cent compared to normal row planting which recorded the lowest productivity. Between the two controls, though not significant, paired row planting enhanced root productivity to the tune of 16.20 per cent over normal row planting.

4.2.8 Oil yield

Row zone oil yield at twelve months after planting and cumulative oil yield per unit area as influenced by row zone and inter row zone management practices and their interactions are furnished in Table 18.

Row zone and inter row zone management practices and their interactions significantly influenced row zone oil yield at harvest and cumulative oil yield per unit area. Positive and significant effect of T_4 (*in situ* composting in trenches+ Stubble mulching + summer irrigation at 80 mm CPE – 22.21g/plot) was observed in increasing oil yield at harvest compared to all other treatments.

Multiple cropping significantly enhanced row zone oil yields to the tune of 22.16 per cent over double cropping and 54.13 per cent over mono cropping.

Table 18. Effect of row zone and inter-row zone management practices and their interactions on row zone oil yield at 12MAP and cumulative oil yield per unit area

Treatments	Row zone (g/plot)	Grand total (Row zone +inter row zone)	
	12 MAP	(g/plot)	(Kg/ha)
Row zone management			
T_1	14.32	19.46	48.64
T_2	17.00	22.82	57.05
T_3	16.18	22.69	56.73
T_4	22.21	29.79	74.47
Inter-row zone management			
B_1	21.06	27.79	69.49
B_2	17.24	24.36	60.89
B_3	13.98	18.91	47.28
Interaction effects			
T_1B_1	16.42	22.31	55.77
T_1B_2	13.47	18.97	47.44
T_1B_3	13.07	17.08	42.71
T_2B_1	20.69	26.69	66.72
T_2B_2	17.15	23.89	59.73
T_2B_3	13.16	17.88	44.69
T_3B_1	18.73	25.66	64.15
T_3B_2	15.54	23.02	57.56
T_3B_3	14.26	19.39	48.48

T_4B_1	28.41	36.53	91.31
T_4B_2	22.81	31.54	78.86
T_4B_3	15.41	21.29	53.23
Treatment mean	17.43	23.69	59.53
Controls			
NRP	7.69	7.69	19.22
PRP	9.93	9.93	24.82
Control mean	8.81	8.81	22.02
SE			
T	0.87	1.02	2.56
B	0.75	0.89	2.22
TB	1.51	1.77	4.43
CD (0.05)			
T	1.88	2.21	5.53
B	1.63	1.92	4.79
TB	3.26	3.83	9.58
Treatments Vs Control	1.76	2.069	5.17
Between controls	NS	NS	NS
Between treatments (including controls)	3.26	3.83	9.58

NS – Not significant MAP – Months After Planting

Integration of the above two factors had positive and significant effect on oil yield and T_4B_1(*in situ* composting in trenches+ Stubble mulching + summer irrigation at 80 mm CPE and multiple cropping) was found superior compared to all other treatment combinations.

The trend was exactly similar between treatments including controls and the per cent increase in oil yield at harvest in T_4B_1 was 269.44 compared to the control (normal row planting). Though not significant, between the two controls, paired row planting enhanced oil yield at harvest.

The trend with respect to cumulative oil yield per unit area was exactly similar to row zone oil yield and increase in cumulative oil yield per unit area in T_4B_1 was 375.08 per cent over the control (normal row planting).

4.2.9 Uptake of nutrients

Mean data on content and uptake of nitrogen, phosphorus and potassium (leaf) as influenced by row zone and inter row zone management practices and their interactions at twelve month after planting are given in Table 19a.

Row zone management practices significantly influenced content and uptake of nitrogen, phosphorus and potassium in leaf. The highest leaf nitrogen, phosphorus and potassium contents of 1.795, 0.482 and 1.58 per cent were recorded by T_4, T_4, and T_3 respectively. Inter row zone management practices also significantly influenced leaf nitrogen, phosphorus and potassium contents and B_1 (1.63, 0.47, 1.49 percent) registered higher values. However leaf nitrogen, phosphorus and potassium uptake was unaffected by inter row zone management practices. Interaction effects of treatments including control also significantly affected the content and uptake of nitrogen, phosphorus and potassium. Integration of T_4 and B_1 resulted in higher concentration of nitrogen, phosphorus and potassium in vetiver leaves. Nitrogen, phosphorus and potassium uptake by leaves ranged from 64.88 to 111.24, 10.75 to 34.33, 52.75 to 118.81 kg ha^{-1} respectively and T_2B_3 registered the highest uptake.

Table 19 a. Effect of row zone and inter-row zone management and their interactions on nutrient uptake (Leaf) at 12 MAP

Treatments	Nitrogen		Phosphorus		Potassium	
	Content (%)	Quantity (kg ha-^{1})	Content (%)	Quantity (kg ha-^{1})	Content (%)	Quantity (kg ha-^{1})
Row zone management						
T_1	1.3	81.16	0.35	21.87	1.16	72.00
T_2	1.44	108.89	0.44	31.49	1.46	110.10
T_3	1.6483B	82.04	0.44	20.67	1.58	78.73
T_4	1.7950A	70.97	0.48	16.41	1.49	58.76
Inter-row zone management						
B_1	1.635	88.59	0.4675	22.08	1.49	80.82
B_2	1.5525	85.01	0.415	22.56	1.4225	78.61
B_3	1.4625	83.70	0.405	23.19	1.3625	80.26
Interaction effects						
T_1B_1	1.45	88.03	0.32	19.61	1.10	66.35
T_1B_2	1.26	81.20	0.37	24.06	1.17	75.97
T_1B_3	1.22	74.26	0.36	21.94	1.21	73.69
T_2B_1	1.47	109.06	0.41	30.39	1.50	110.60
T_2B_2	1.48	106.39	0.42	29.74	1.41	100.90
T_2B_3	1.38	111.24	0.49	34.33	1.47	118.81
T_3B_1	1.73	85.41	0.55	21.76	1.67	82.47
T_3B_2	1.66	81.11	0.40	19.85	1.60	77.94
T_3B_3	1.56	79.61	0.38	20.41	1.49	75.78
T_4B_1	1.89	71.86	0.59	16.59	1.69	63.88
T_4B_2	1.81	71.35	0.47	16.56	1.51	59.64
T_4B_3	1.69	69.70	0.39	16.10	1.28	52.75

Treatment mean	1.55	85.77	0.43	22.61	1.43	79.89
Controls						
NRP	1.12	64.88	0.19	10.75	1.02	59.03
PRP	1.15	66.47	0.21	11.92	1.03	59.62
Control mean	1.13	65.68	0.19	11.34	1.02	59.33
SE						
T	0.038	4.95	0.022	1.52	0.038	3.95
B	0.033	4.29	0.019	1.32	0.033	3.42
TB	0.066	8.58	0.037	2.63	0.066	6.85
CD (0.05)						
T	0.082	10.69	0.047	3.28	0.082	8.54
B	0.071	NS	0.040	NS	0.071	NS
TB	NS	NS	0.081	NS	0.142	NS
Treatments Vs Control	0.077	10.01	0.044	3.071	0.077	7.99
Between controls	NS	NS	NS	NS	NS	NS
Between treatments (including controls)	0.142	18.53	0.081	5.69	0.147	14.79

NS – Not significant MAP – Months After Planting

Mean data on content and uptake of nitrogen, phosphorus and potassium in root at twelve month after planting are furnished in Table 19b. Significant effect of row zone management on root nitrogen, phosphorus and potassium contents were observed at twelve month after planting and that ranged from 1.82 to 2.38, 0.32 to 0.43 and 1.25 to 1.51 per cent respectively. Root nitrogen was highest in T_3 (2.378%), root phosphorus in T_4 (0.425%) and root potassium in T_3 (1.51%). Uptake of nitrogen, phosphorus and potassium by root also showed significant variation and ranged from 53.36 to 94.55, 9.29 to 17.27, and 36.88 to 59.27 kg ha^{-1} respectively. T_4 recorded the highest uptake of all the three major nutrients which differed significantly from other levels. Root phosphorus and potassium contents were significantly influenced by inter row zone management practices and B_1 in both cases registered higher values.

Mean data on total nitrogen, phosphorus and potassium uptake as influenced by row zone and inter row zone management practices and their interactions are presented in table 19c.

Row zone management practices significantly influenced total plant uptake of nitrogen, phosphorus and potassium and that ranged from 134.52 to 175.85, 31.16 to 42.79 and 108.89 to 154.97 kg ha^{-1} respectively. T_2 in all the cases were effective in enhancing plant uptake of nitrogen, phosphorus and potassium. Similar to row zone treatments, inter row zone treatments also remarkably influenced total plant uptake of nitrogen, phosphorus and potassium which ranged from 152.06 to 168.56, 34.08 to 36.37 and 121.71 to 135 kg ha^{-1} respectively. Multiple cropping significantly enhanced total uptake of nitrogen, phosphorus and potassium. Interaction effects of treatments including control also significantly enhanced total nitrogen, phosphorus and potassium content and values ranged from 88.16 to 186.44, 13.74 to 44.64 and 75.25 to 164.31 kg ha^{-1} respectively. T_2B_1 recorded higher uptake of nitrogen, phosphorus and potassium and per cent increase over normal row plantings were 111.48, 224.89 and 118.35 respectively.

Table 19 b. Effect of row zone and inter-row zone management and their interactions on nutrient uptake (Root) at 12 MAP

Treatments	Nitrogen		Phosphorus		Potassium	
	Content (%)	Quantity (kg ha^{-1})	Content (%)	Quantity (kg ha^{-1})	Content (%)	Quantity (kg ha^{-1})
Row zone management						
T_1	1.82	53.36	0.315	9.29	1.25	36.89
T_2	2.01	66.95	0.337	11.31	1.34	44.87
T_3	2.38	74.59	0.382	11.96	1.51	47.24
T_4	2.34	94.55	0.425	17.27	1.47	59.27
Inter-row zone management						
B_1	2.13	79.98	0.395	14.29	1.45	54.18
B_2	2.15	68.76	0.375	12.19	1.36	43.09
B_3	2.12	68.36	0.34	10.89	1.37	43.92
Interaction effects						
T_1B_1	1.80	56.21	0.33	10.31	1.27	39.81
T_1B_2	1.88	49.23	0.30	7.74	1.21	31.57
T_1B_3	1.77	54.62	0.32	9.82	1.27	39.27
T_2B_1	2.03	77.38	0.38	14.26	1.41	53.72
T_2B_2	2.10	62.95	0.33	9.97	1.39	41.85
T_2B_3	1.90	60.53	0.31	9.70	1.23	39.04
T_3B_1	2.31	74.50	0.40	12.77	1.55	50.07
T_3B_2	2.27	66.78	0.39	11.51	1.49	43.92
T_3B_3	2.56	82.51	0.36	11.60	1.48	47.73
T_4B_1	2.40	111.81	0.43	19.81	1.57	73.12
T_4B_2	2.36	96.07	0.48	19.57	1.35	55.04
T_4B_3	2.26	75.76	0.37	12.43	1.48	49.64

Treatment mean	2.14	72.36	0.37	12.46	1.39	47.07
Controls						
NRP	1.64	23.27	0.21	2.99	1.14	16.22
PRP	1.66	27.40	0.23	3.77	1.17	19.26
Control mean	1.65	25.34	0.22	3.38	1.16	17.74
SE						
T	0.034	2.44	0.016	0.651	0.029	2.06
B	0.029	2.11	0.014	0.564	0.025	1.78
TB	0.058	4.23	0.028	1.13	0.051	3.56
CD (0.05)						
T	0.074	5.28	0.035	1.41	0.064	4.44
B	NS	4.57	0.031	1.22	0.055	3.85
TB	0.126	9.14	NS	2.44	0.110	7.69
Treatments Vs Control	0.068	4.94	0.033	1.32	0.059	4.16
Between controls	NS	NS	NS	NS	NS	NS
Between treatments (including controls)	0.126	9.14	0.061	2.44	0.110	7.69

NS – Not significant

MAP – Months After Planting

Table 19c. Effect of row zone and inter-row zone management practices and their interactions on nutrient uptake (Root+Leaf) at 12 MAP Total

Treatments	Nitrogen(kg ha-^{1})	Phosphorus(kg ha-^{1})	Potassium(kg ha-^{1})
Row zone management			
T_1	134.52	31.16	108.89
T_2	175.85	42.79	154.97
T_3	156.64	32.63	125.97
T_4	165.52	33.68	118.02
Inter-row zone management			
B_1	168.56	36.37	135.00
B_2	153.77	34.75	121.71
B_3	152.06	34.08	124.18
Interaction effects			
T_1B_1	144.24	29.92	106.16
T_1B_2	130.44	31.80	107.54
T_1B_3	128.88	31.76	112.96
T_2B_1	186.44	44.64	164.31
T_2B_2	169.34	39.71	142.75
T_2B_3	171.77	44.03	157.85
T_3B_1	159.90	34.53	132.54
T_3B_2	147.89	31.36	121.85
T_3B_3	162.12	32.01	123.52
T_4B_1	183.67	36.40	137.00
T_4B_2	167.41	36.13	114.68

T_4B_3	145.46	28.52	102.39
Treatment mean	158.13	35.07	126.96
Controls			
NRP	88.16	13.74	75.25
PRP	93.88	15.68	78.89
Control mean	91.02	14.71	77.07
SE			
T	4.79	1.56	4.54
B	4.148	1.35	3.93
TB	8.29	2.70	7.87
CD (0.05)			
T	10.35	3.37	9.81
B	8.96	NS	8.49
TB	NS	NS	16.99
Treatments Vs Control	9.68	3.15	9.18
Between controls	NS	NS	NS
Between treatments (including controls)	17.92	5.83	16.99

NS – Not significant MAP – Months After Planting

4.2.10 Economic analysis

The economic analysis of root production in terms of cost of cultivation, gross income, net income, BCR as influenced by row zone and inter row zone management practices and their interactions are presented in Table 20.

Row zone and inter row zone management practices and their interactions significantly influenced all the economic parameters studied. T_1 (*in situ* composting in trenches) recorded the least cost of cultivation of Rs 4.72 lakhs followed by T_2 and T_3. The highest cost of cultivation of Rs 4.99 lakhs was registered by T_4. Cost of cultivation was higher in T_4 to the tune of 5.72 per cent compared to T_1. T_4 recorded higher gross income, net income, and BCR and compared to T_1 the per cent increase were 48.47, 90.60, and 39.80, respectively. Multiple cropping significantly increased the cost of cultivation to the tune of 1.23 per cent and 4.46 per cent over double cropping and mono cropping respectively. The highest gross income of Rs 13.48 lakhs was obtained when multiple cropping was adopted and it was15.41 and 49.78 per cent higher compared to double cropping and mono cropping respectively. The trend was exactly similar with respect to net income and BCR. The highest net income of Rs 8.56 lakhs and BCR of 2.73 were recorded by multiple cropping. Integration of T_4 and B_1 significantly enhanced the cost of cultivation to the tune of 101.96 per cent over the control (normal row planting). The same treatment combination registered significantly higher gross income, net income and BCR and per cent increase over the control (normal row planting) were 366.04, 931.93, and 129.93.

Method of planting was also found to exert significant influence on all economic parameters studied and though cost of cultivation was higher for paired row planting, it registered significantly higher gross income, net income and BCR.

Table 20. Effect of row zone and inter-row zone management practices and their interactions on economics of vetiver oil production

Treatments	Cost of cultivation (Rs in lakhs)	Gross income (Rs in lakhs)	Net income (Rs in lakhs)	BCR
Row zone management				
T_1	4.72	9.51	4.79	2.01
T_2	4.79	11.03	6.24	2.29
T_3	4.81	10.88	6.07	2.26
T_4	4.99	14.12	9.13	2.81
Inter-row zone management				
B_1	4.92	13.48	8.56	2.73
B_2	4.86	11.68	6.83	2.39
B_3	4.71	9	4.29	1.91
Interaction effects				
T_1B_1	4.75	11.01	6.26	2.32
T_1B_2	4.77	9.26	4.49	1.94
T_1B_3	4.64	8.27	3.63	1.78
T_2B_1	4.90	13.06	8.16	2.67
T_2B_2	4.81	11.44	6.63	2.38
T_2B_3	4.65	8.60	3.95	1.85
T_3B_1	4.89	12.43	7.54	2.54
T_3B_2	4.82	11.07	6.25	2.30

T_3B_3	4.73	9.15	4.43	1.94
T_4B_1	5.15	17.43	12.28	3.38
T_4B_2	5.04	14.96	9.93	2.97
T_4B_3	4.81	9.98	5.18	2.08
Treatment mean	4.83	11.39	6.56	2.35
Controls				
NRP	2.55	3.74	1.19	1.47
PRP	2.65	4.71	2.06	1.78
Control mean	2.6	4.23	1.63	1.63
SE				
T	0.019	0.015	0.026	0.01
B	0.017	0.013	0.022	0.009
TB	0.033	0.026	0.045	0.017
CD (0.05)				
T	0.041	0.033	0.056	0.022
B	0.036	0.029	0.048	0.019
TB	0.072	0.057	0.097	0.037
Treatments *Vs* Control	0.039	0.031	0.052	0.020
Between controls	0.021	0.017	0.028	0.011
Between treatments (including controls)	0.072	0.057	0.097	0.037

MAP – Months After Planting

DISCUSSION

5. DISCUSSION

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

5.1 BIOINOCULANTS FOR QUALITY PLANTING MATERIAL PRODUCTION

Production of quality planting material is of paramount importance in commercial mediculture. Biomass production potential of vetiver is quite high and hence it needs large quantities of nutrients compared to other medicinal and aromatic plants. Dependence on chemical fertilizers can be avoided or reduced if suitable bioinoculants are introduced in vetiver system.

Microbial inoculation of vetiver slips with suitable bioagents in nursery and then transplanting such bioinoculated saplings in the main field is more appropriate than biofertilizer application in the main field for achieving higher activity. The effect of single, dual, and combined inoculation of four bioinoculants, namely, Azospirillum, phosphorus solubilising bacteria, arbuscular mycorrhizal fungi and fluorescent pseudomonas on morphological characters, root parameters, biomass accumulation and partitioning, physiological parameters, performance of planting materials in nursery and rhizosphere micro flora were studied in nursery.

Single, dual and combined inoculation of bioinoculants influenced sapling growth and vigour in different ways. In general phosphorus solubilising bacteria favourably and significantly influenced sapling height, root number, root spread, shoot weight, root weight, total biomass accumulation, relative leaf water content, and sturdiness quotient and sapling growth potential (Tables 6,7,8,9,10). Functional leaf number was found favourably influenced by arbuscular mycorrhizal fungi (Table 6). Significant and positive influence of dual inoculation with Azospirillum and fluorescent pseudomonas was evident on length of root, root growth potential and population of Azospirillum (Table 11).

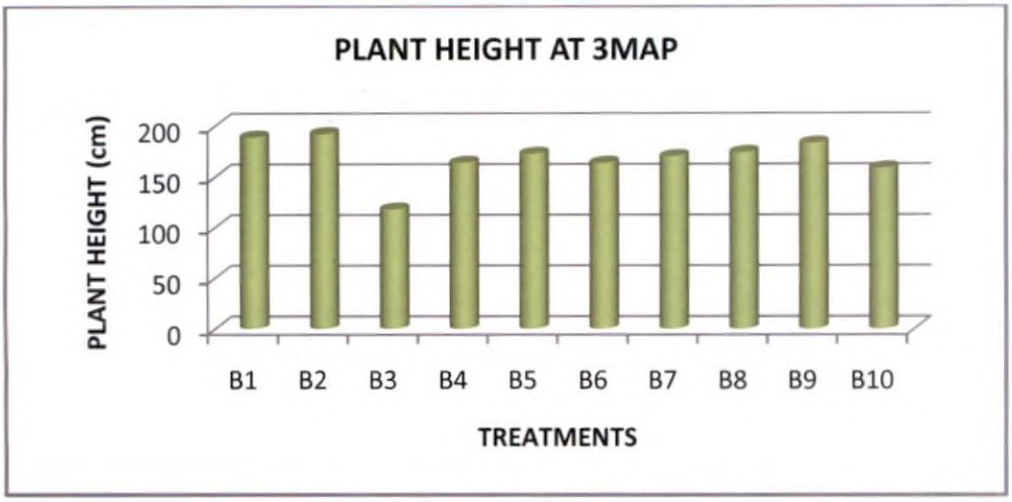


Fig.3. Effect of bio inoculants on plant height in nursery

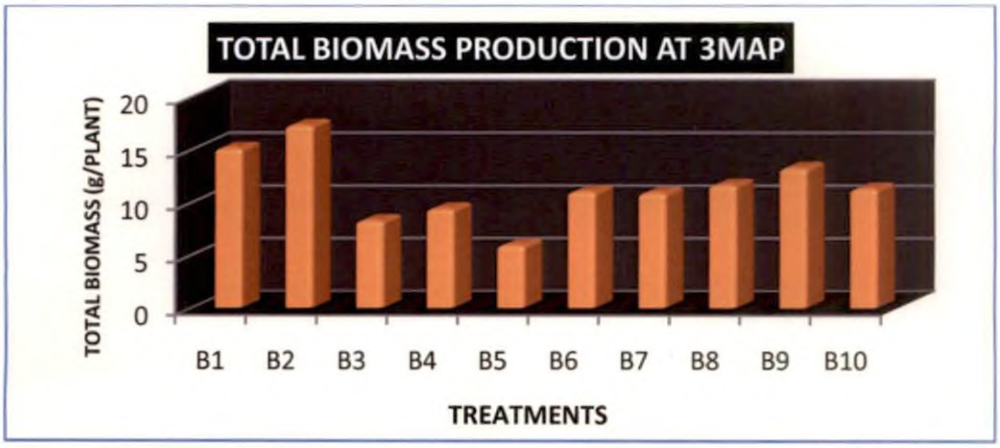


Fig. 4 Effect of bio inoculants on biomass accumulation in nursery

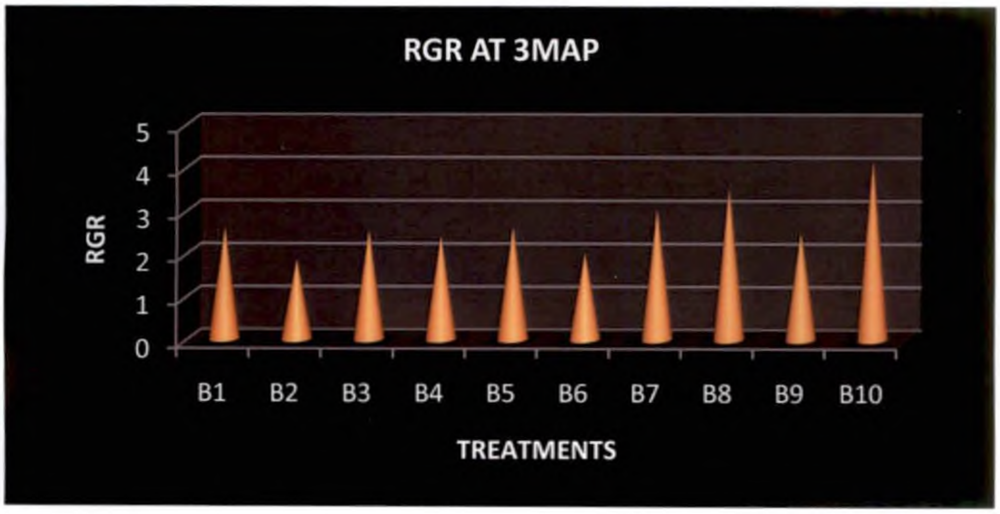


Fig. 5 Effect of bio inoculants on Relative growth rate in nursery

Relative growth rate was found favourably and significantly influenced by combined application of Azospirillum, phosphorus solubilising bacteria and arbuscular mycorrhizal fungi (Table 9 and Fig 5).

Several reports relating to screening and advantages of using plant growth promoting rhizobacteria (PGPR) with crop plants particularly rice, maize, and sugarcane are available. However, little information about screening and application of plant growth promoting rhizobacteria with vetiver grass is available. Plant growth promoting rhizobacteria are found in the rhizosphere and in association with roots. These bacteria can improve the extent and quality of plant growth directly (Ahmad *et al.* 2008) by increasing nutrient cycling such as biological nitrogen fixation, solubilisation of phosphorus, synthesis of phytohormone or by indirect mechanisms like synthesis of biochemical compounds to inhibit phytopathogens (Dobbelacere *et al.* 2003 and Lucy *et al.* 2004). A large array of bacteria including fluorescent pseudomonas (Ahmad *et al.* 2008), Azospirillum (Okon *et al.* 1994), Azotobacter and Bacillus (Ahmad *et al.* 2008), Beijerinckia (Thuler *et al.* 2003), Klebsiella (Govindrajan *et al.* 2007) have shown plant growth promoting properties.

Vetiver is a hardy plant by nature but during its early stages of growth it is rather weak as propagated by slips. Thus during establishment stage, it would be better to have beneficial microorganisms to support growth and development of vetiver plants. The present findings highlight the significance of Azospirillum, arbuscular mycorrhizal fungi and fluorescent pseudomonas as potential agents for rhizosphere engineering in vetiver. Similar results have been reported by (Shimi, 2011). She reported positive and significant influence of leaf dry matter at all stages and root dry matter at certain stages of growth.

Single inoculation and dual inoculation of bioinoculants were instrumental in improving certain growth attributes at certain stages of growth. The inconsistencies in the performance of bioinoculants at certain stages are due to several factors,

Saplings immediately
after planting in poly bags

Performance of spalings as influenced by
inoculation with bio inoculants (1MAP)

Performance of spalings as influenced by inoculation with Azospirillum (3MAP)

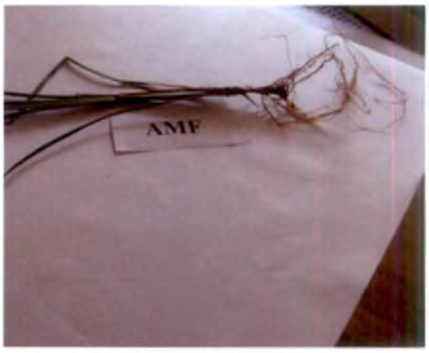
Performance of spalings as influenced by inoculation with PSB (3MAP)

Plate.1 Nursery management for quality sapling production in vetiver namely, microbial population, soil fertility status, etc. Rhizosphere micro flora namely Azospirillum, phosphorus solubilising bacteria, arbuscular mycorrhizal fungi and fluorescent pseudomonas were enumerated and it is observed that single inoculation was beneficial in improving the populations of phosphorus solubilising bacteria, arbuscular mycorrhizal fungi and fluorescent pseudomonas. However, dual inoculation with Azospirillum and fluorescent pseudomonas was found favourable for increasing the Azospirillum population. Soil microorganism and their activities play an important role in transformation of plant nutrients from unavailable to available forms and also have metabolic qualities related to soil fertility improvement. Sunatapongsuk (2000) reported that microbial populations and activities were higher in the vetiver rhizosphere; total and cellulolytic microorganisms ranged from 10^6-10^8 cell g^{-1} soil, the numbers of nitrogen fixing bacteria and phosphate solubilising microorganisms numbered 101-104 cell g^{-1} soil and endomycorrhiza 3-26 spores g^{-1} soil.

The positive influence of arbuscular mycorrhizal fungi on functional leaf number was due to increased partitioning of phosphorus between root and shoot system. This would have resulted in better utilization of photosynthates by aerial parts. Similar results have been reported by (Smith, 1980). Similar to higher root production in vetiver, better root development in black pepper consequent to bioinoculant applications were reported by several workers. Production of significant quantities of plant growth hormones such as gibberellins, cytokines, and auxins like IAA might have resulted in better development of root system. Consequent to Azospirillum inoculation, the root length increased especially in the root elongation zone (Tien *et al.* 1979).

Root growth potential, sturdiness quotient and sapling growth potential of vetiver saplings were significantly influenced by treatment effects at all stages of growth. With respect to root growth potential, the effect of dual inoculation with

Single inoculation with PSB



Single inoculation with AMF

Uninoculated control

Dual inoculation with Azospirillum + PSB

Combined inoculation with Azospirillum+PSB+AMF

Plate.2 Effect of bio inoculants on root development in vetiver

Azospirillum and fluorescent pseudomonas was pronounced throughout nursery period. Sturdiness quotient also improved consequent to inoculation with phosphorus solubilising bacteria. The impact of inoculation was remarkable with respect to sapling growth potential as well. Compared to the control, single inoculation with phosphorus solubilising bacteria significantly enhanced sapling growth potential to the tune of 177 per cent, 50 per cent and 27 per cent at first, second and third months after planting respectively (Table 10 and Fig.6).

Root growth potential is the ability of seedling to initiate and elongate roots when placed in an environment favourable for root growth. Root growth potential is often affected by soil temperature, soil moisture and other factors. Higher root growth potential is an important seedling quality attribute presumably because it enables the seedlings to become established rapidly after planting. The rationale for this is that when a seedling is planted it has a finite root system. Although it is capable of exploiting moisture and nutrients from its immediate viscinity, these reserves are soon depleted. For establishment to occur, new soil reserves must be tapped, hence new roots must be grown. Seedlings which are unable to grow roots are doomed to water stress and ultimately death occurs. The condition of the seedling shoot and foliage is also important for root growth potential. Since leaves of many species export an essential rooting co-factor, removal of, or damage to the foliage can impede root growth. Root growth potential represents only a potential to grow roots and its expression depends on many factors, *viz*., soil moisture, soil fertility, soil temperature, etc.

Sapling's sturdiness to withstand environmental stress on field planting is indicated by sturdiness quotient. Crop growth potential is influenced by total dry matter production, sturdiness quotient and shoot root ratio.

Based on the analysis of above discussed parameters, it is concluded that phosphorus solubilising bacteria was the most effective microorganism compared to

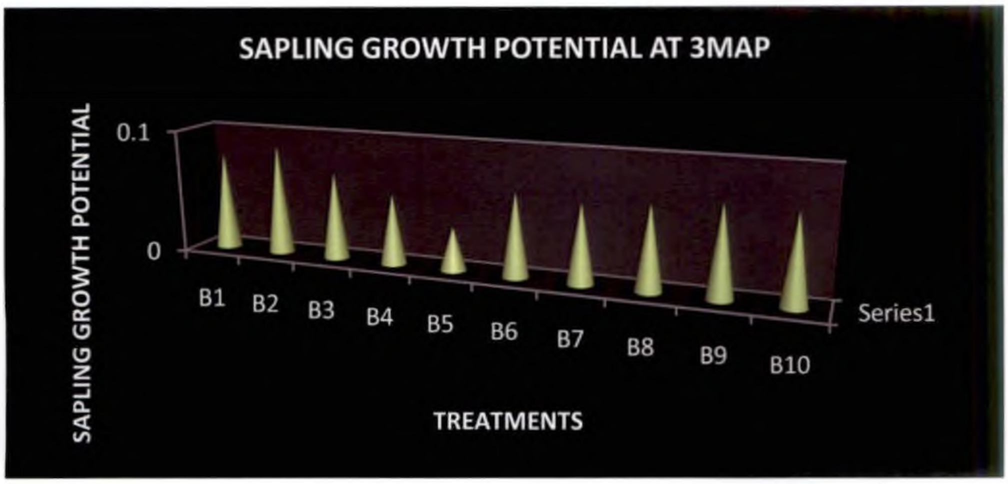


Fig. 6 Effect of bio inoculants on Relative growth rate in nursery

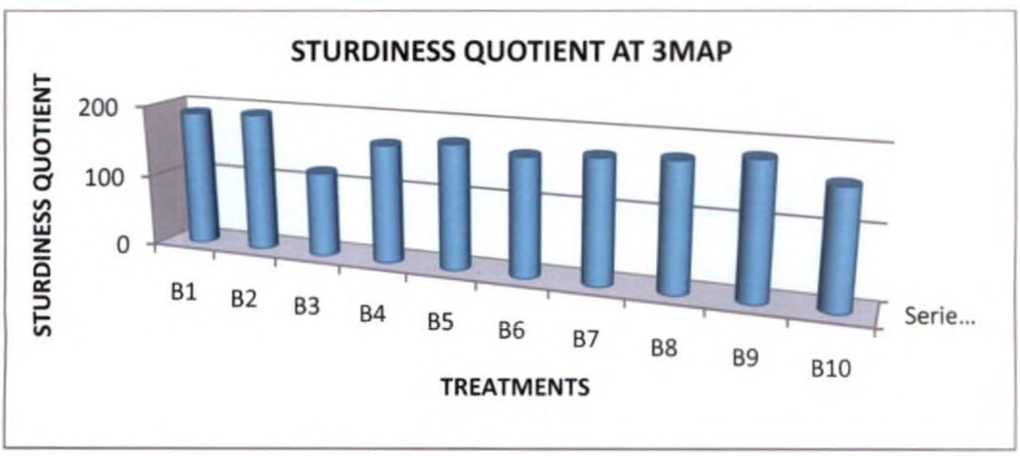


Fig. 7 Sturdiness quotient as influenced by effect of bio inoculants in nursery

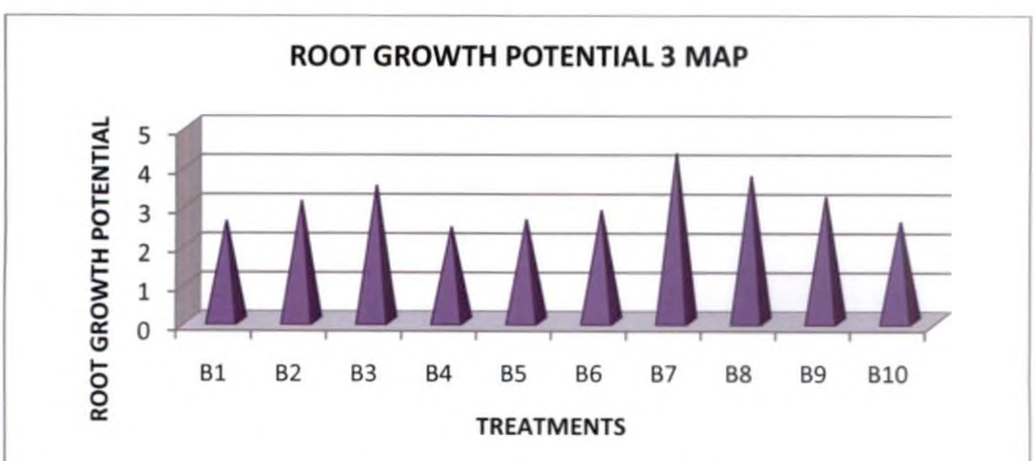


Fig. 8 Effect of bio inoculants on root growth potential in nursery

other bioinoculant treatments in improving several key parameters including sapling growth potential.

5.2 MULTIPLE CROPPING AND MICROSITE ENRICHMENT TECHNIQUES FOR ROW AND INTER-ROW ZONE MANAGEMENT

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

5.2.1 Morphological characters

The effect of row zone management practices, inter row zone management practices and their interactions were inconsistent in significantly influencing various morphological characters of vetiver during different stages of its growth. In general taller plants with more number of tillers and leaves were observed when vetiver was planted in trenches were *in situ* composting was practiced. With respect to cropping systems, mono cropping was beneficial for plant elongation were as leaf number and tiller production enhanced with multiple cropping. Between the two planting patterns, normal row planting pattern was found beneficial for improving height and leaf number. Integration of *in situ* composting in trenches + Stubble mulching and multiple cropping increased tiller production. Enormous numbers of leaves were produced when the above treatment combination was integrated with irrigation at 40 mm CPE.

Morphological characters, namely, plant height, leaf number and tiller production indicate the photosynthetic efficiency of vetiver crop and the transpirational area related to field establishment and further growth especially with respect to water productivity. Crop growth is influenced by metabolic activities which need sufficient amounts of plant nutrients and water besides, favourable phytoclimate which is created by regulation of canopy growth. Planting vetiver in trenches after *in situ* composting followed by surface mulching with vetiver prunings

Microsite enrichment

BBT (Broad Beds and Trenches) system of planting vetiver

Plate.3 Micro site enrichment and land configuration in vetiver at four months interval are beneficial for maintaining optimum moisture-nutrient-oxygen regime in the rhizosphere.

Tillering in tropical grasses is a structural characteristic that determines the morphological plasticity; it is influenced by combinations of nutritional, environmental and management factors. It is known that soil nitrogen status stimulates the emergence and renewal of tillers. Tillering also affects the canopy structure since it determines the intensity of the intra specific competition for food resources and nutrients. Number of tillers and leaves also change the quality and quantity of electromagnetic spectrum that penetrates through the canopy (Garcez *et al.* 2002).

Pruning can promote growth and tillering in vetiver as it is quite tall and attains filled in stage within three months of planting. Being a C_4 plant it demands plenty of light for its growth and development. Proper pruning facilitate almost equitable light distribution over the canopy ensuring higher photosynthetic efficiency. There is no serious impact of frequent prunings in vetiver; on the contrary, removal of senile culm and leaves reduces the demand for moisture and nutrients by unproductive structures. Pruning also blocks the transformation of vetiver from vegetative to reproductive stages which would have consumed large quantities of water and nutrients for flowering and seeding. Pruning is one of the measures for achieving luxuriant root and heavy tillering in vetiver (Sbrissia, 2008).

Growth enhancement in relation to higher leaf number might be due to frequent irrigation at 40 mm CPE and subsequent conservation of moisture by leaf mulch besides improvement in soil fertility through *in situ* composting (Table 6). Hence, vetiver never faced any constraints for cell division, cell expansion and photosynthesis. Begg and Turner (1976) reported similar situation in several crops. The primary plant process affected by nutrient and water stress is cell elongation due to reduction in turgor pressure. Cell expansion is also badly affected due to lower turgor pressure and water stress (Nath, 1993). Lower rate of leaf production under *in situ* composting in trenches + Stubble mulching might be due to water stress inhibition of cell division and cell expansion. Reduction in leaf area by way of reducing the rate of leaf production is one of the measures prevalent in crop plants to mitigate internal crop water deficit arising out of soil moisture stress.

In Kerala, where soil moisture stress is prevalent during summer season, increases in precipitation use efficiency (PUE) is essential to alleviate drought. Several studies have been carried out in ridge furrow system which is almost identical to broad bed trench system for increasing precipitation use efficiency (PUE). Studies have shown that using crop straw, plastic film or gravel- sand materials to mulch the soil surfaces significantly reduces the evaporation of soil moisture, increases water availability in crop plants and decreases soil erosion caused by wind and water. Plastic mulching increases top soil temperature and straw mulching can moderate soil temperature. Ridge furrows with plastic mulching on the ridges and crop straw covering the furrows, channel water to the furrows and enhance soil water infiltration and water availability to the crop. Microclimate under mulched ridges and furrows favour soil microbial activity, increases soil biodiversity and improve environmental benefits. Similar to ridge furrow system, broad bed and trench system also facilitate increased crop water availability.

5.2.2 Root parameters

Effect of row zone management practices on root parameters were not consistent at all stages of crop growth. *In situ* composting and planting vetiver in trenches and surface mulching it with its own prunings promoted root number and root elongation when the above row zone management practices was integrated with summer irrigation at 40 mm CPE. Considerable increase in root weight was noticed when the interval of moisture supply was extended by providing summer irrigation at 80 mm CPE. Cropping system approach was also found beneficial for enhancing root proliferation in vetiver. Increasing cropping intensity by resorting to multiple cropping led to root proliferation in terms of root number, root length and root weight. Planting patterns also regulated root development and paired row pattern facilitated extensive development of roots in vetiver. There was considerable improvement in all root parameters studied when paired row planting was resorted to.

Use of appropriate rooting media is very important for the supply of nutrients, water and air to the root system which contributed to better development of roots. Miller and Jones (1995) reported characteristics such as light weight, porous, well drained but capable of retaining moisture, maintaining volume wet or dry and free from soil borne pathogens as desirable traits of rooting medium.

The beneficial effects of *in situ* composting in trenches have been reported by several workers. It is quite simple and easy as it gives nutrients right where they need it, *ie*, at the root zone. Hence, the plants are healthier in two ways. It gets nourishment from organic matter in the trenches and develops a deep and strong root system. The plant is able to cope up with dry condition and heat and requires less after care. Besides, *in situ* composting is invisible and is not producing undesirable odors (Basso and Ritchie, 2005).

In situ composting carried out in the trenches prior to vetiver planting created favourable situations for the development ideal rooting medium. The findings are in conformity with the results reported in ratoon sugar cane crop where thrashes are placed in between cane rows and applied manures and fertilizer and bio inoculants and driven into the rhizosphere with a special implement. The technology was found economically viable as it increase nutrient use efficiency and benefit cost ratio.

The impact of soil moisture regimes on root growth was not consistent. *In situ* composting + stubble mulching increased number and length of roots as the crop might have faced occasional soil moisture stress. Moisture stress in the root zone promoted root number and root elongation.

5.2.3 Physiological Parameters

Like the leaf chlorophyll, relative leaf water content was also found to be influenced by row zone and inter row zone management practices and their interactions. Planting vetiver in trenches where *in situ* composting was carried out and stubble mulching practiced at an interval of four months resulted in greater formation of chlorophyll and higher relative leaf water content compared to mono cropping and double cropping of vetiver on broad beds indicate the positive impact of multiple cropping in enhancing leaf chlorophyll content.

Relative leaf water content is a commonly used indicator for plant water status because it is easy to measure on various plant materials. The relationship between relative water content and water potential differs with species. Under stress conditions a species with higher relative water content indicates that it is more drought resistant. Studies have shown that maximum relative water content is a useful criterion to differentiate between drought resistant and drought susceptible cultivars. A species with higher relative leaf water content at water potential of -1.5 MPa is more drought resistant.

Water stress is a dominant environmental factor influencing growth and survival of tropical grasses. Vetiver grass is widely grown in monsoon countries where most of the areas have a hot and dry summer after the rainy season, resulting in water shortage during summer. Therefore vetiver plants grown in this area are subjected to broad ranges in water availability throughout the year, from prolonged flooding to drought. Seasonal leaf water potential as low as -10 MPa have been recorded in some C_4 grasses under such environmental conditions. Although vetiver

Biomass production of vetiver (T4B1)

Biomass production of vetiver (T4B2)

Biomass production of vetiver (T3B1)

Plate.4 Effect of treatment combinations on biomass production in vetiver shows tolerance to a broad range of water stresses, seasonal drought severely limits its growth (Ludlow, 1976).

5.2.4 Dry matter production

Low water holding capacity, poor soil water retention, high percolation rates leading to washing away of essential plant nutrients are some of the major constraints in the humid tropics adversely affecting agricultural production. Water intake of soil can be increased by improving soil physical properties such as organic matter content, infiltration rates, permeability, bulk density, water holding capacity, soil stable aggregates, etc. This helps in better crop growth due to conservation of soil moisture and plant nutrients (Acharya and Kapur, 2000).

Growth of plant is influenced by the metabolic activities which require adequate amounts of nutrients and moisture. The performance of vetiver with respect to biometric characters and root parameters reveal that the crop responded very well to treatment combinations, *ie, in situ* composting in trenches + stubble mulching + summer irrigation at 80 mm CPE and multiple cropping. This has resulted in higher leaf and root dry matter production to the tune of 112.48 and 106.53 per cent over control. When normal row planting was practiced, dry matter production reduced considerably due to the effect of nutrients and water stress, water deficit. Generally nutrient and moisture stress have a negative effect on dry matter production in plants as it impairs many of the physiological process which determine the growth. The reduction in dry matter could be due to lesser number of leaves, poor leaf and root weight etc. which are positively correlated with dry matter production in different species.

Nutrient availability is an important factor governing dry matter production in vetiver. Influence of organic and inorganic fertilizers on growth and dry matter production in vetiver have been studied in detail. It is demonstrated that both organic (compost) and inorganic fertilizer applications could significantly improve vetiver

General view of the experimental field - 2 MAP

General view of experimental field - 4 MAP

General view of the experimental field - 6 MAP

General view of the experimental field - 8 MAP

General view of the experimental field - 12 MAP

General view of the experimental field - 10 MAP

Plate.5 General view of the experimental field at different stages of vetiver growth

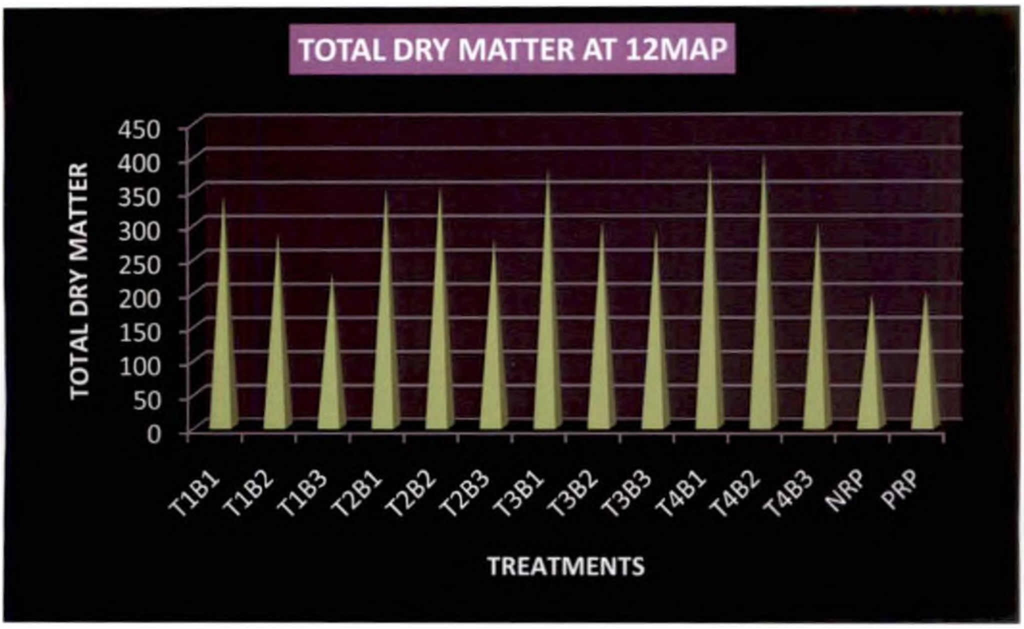


Fig. 9 Effect of treatment combinations on total biomass production

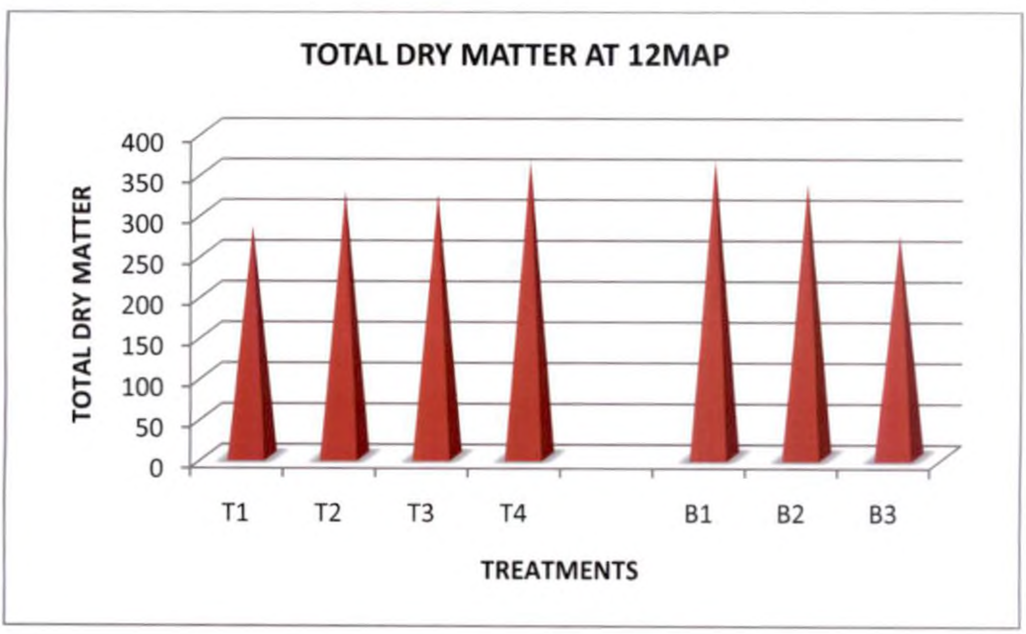


Fig. 10 Total biomass production as influenced by the effect of row zone and inter row zone management practices

biomass. It is recommended to fill the bottom of the plant holes with manure or compost when vetiver is cultivated on deteriorated land on low fertility for better establishment of vetiver slips because, increase in organic matter and nutrient content in soil increases water holding capacity, cation exchange capacity, and improvement in soil structure by forming stable aggregates. These amendments also mitigate the toxicity of heavy metal and plant failure on their absence. Ye *et al.* (2000). Experiments conducted all over the world reveal that application of compost could significantly increase root and shoot dry weight of vetiver (Basso and Ritchie, 2005).

5.2.5 Soil moisture studies

The two treatments, viz, i*n situ* composting + stubble mulching + summer irrigation at 80 mm CPE and multiple cropping in broad beds were found favourable for retaining higher amount of soil moisture both before and after irrigation. Integration of the above two treatments also favoured better conservation of soil moisture. Economy in the use of water, particularly during hot summer is possible by the adoption of *in situ* rain water harvesting and conservation. The beneficial effects of organic manures and i*n situ* composting in soil moisture conservation and utilization are furnished in sections 2.2.1 and 2.2.1.1. Mulching with vetiver prunings at an interval of four months in multiple cropping treatments might have reduced soil evaporation to the minimum level as the soil surface was never exposed to insolation. The efficacy of green leaf manures in conserving soil moisture is furnished in sections 2.2.1.2.

Integration of *in situ* composting and multiple cropping enhanced consumptive use and mean daily consumptive use. This was due to better growth attributes as furnished in sections 3.6.3.1.1 and 3.6.3.2.1. *In situ* composting + stubble mulching + summer irrigation at 80 mm CPE was found to influence the major factors deciding consumptive use and mean daily consumptive use, *viz*, root

Multiple cropping and mulching with vetiver prunings (T4B1)

Multiple cropping and mulching with vetiver prunings (T3B2)

Multiple cropping and mulching with vetiver prunings (T2B1)

Plate.6 Stubble mulch farming in vetiver

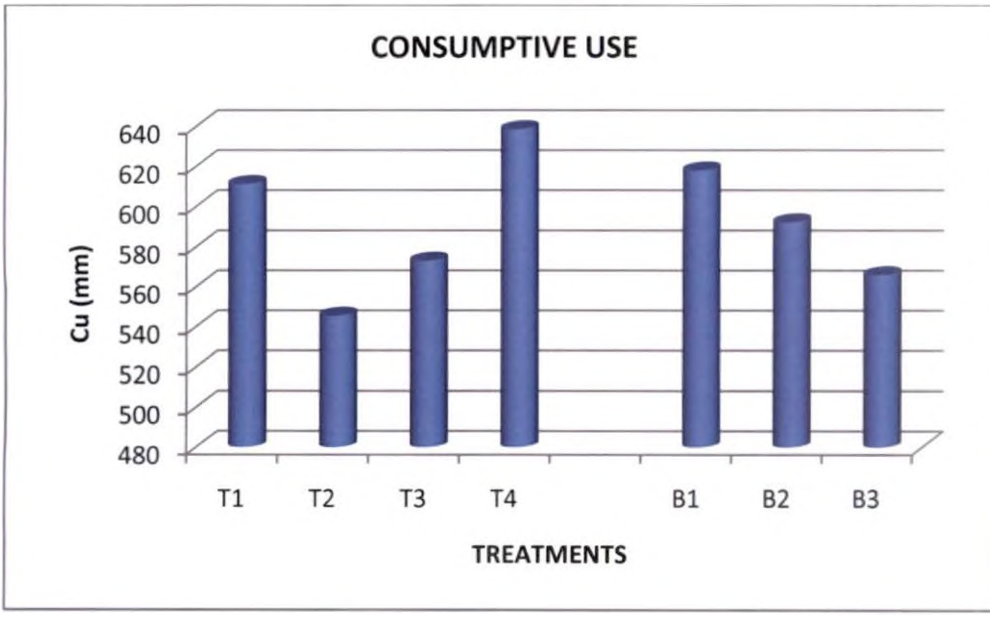


Fig. 11 Consumptive use as influenced by the effect of row zone and inter row zone management practices

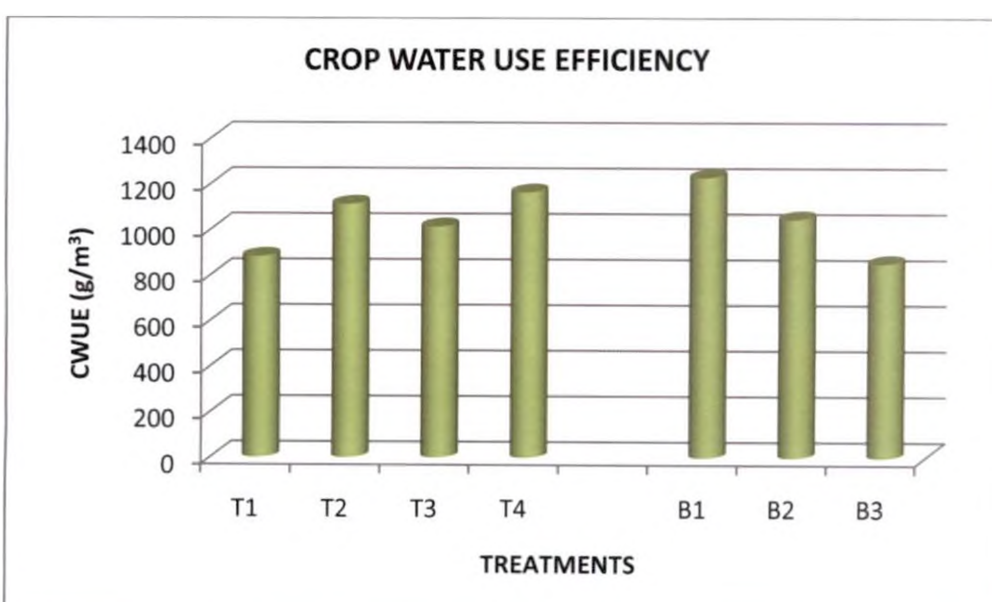


Fig. 12 Crop water use efficiency as influenced by the effect of row zone and inter row zone management practices

yield, total biomass production, evapotranspiration and water requirement. Analysis of the data furnished in Table 16 reveal that all the above factors were favourable for achieving higher consumptive use and mean daily consumptive use in the above treatment combination. Factors contributing to higher root yield and biomass production are discussed in sections 4.2.4 and, 4.2.7.

5.2.6 Root and oil production and productivity

Positive and significant influence of row zone and inter row zone management practices and their interactions benefitted vetiver in improving root production and productivity besides, improvement in oil yield. Paired row planting of vetiver in trenches subsequent to *in situ* composting; and stubble mulching with its own prunings at four months interval integrated with multiple cropping of vetiver in between paired row planted vetiver in trenches on broad beds was found beneficial for higher root and oil production and productivity. The contributing factors for the superior performance of the above treatments are discussed in sections 4.2.4 and 4.2.5.

Mulching is one of the integral components of conservation farming and is increasingly seen the light of integrated soil management – an essential building stone for sustainable agriculture. The use of mulch has enormous agro ecological potential – it typically conserves soil, improves soil ecology, stabilizes and enhances crop yield and provides various environmental services. The origin and source of mulch influence root and oil production in vetiver. The vegetative mulch materials are provided from various sources. In the present contest *ex situ* mulch – mulch produced *ex situ* and imported to the site cut and carry – implying a spatial separation between the production and use of mulch, *in situ* produced mulch (mulch produced *in situ* prior to crop establishment implying a temporal separation between the production and use of mulch) and *in situ* residual mulch (mulches generated as a byproduct from crop residues and weeds from the previous crop cycle) were used for

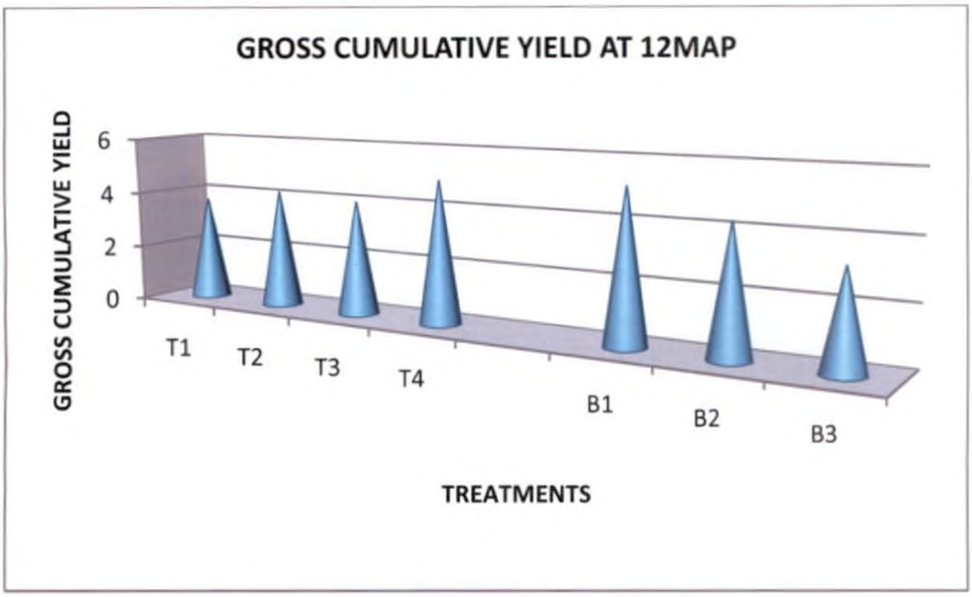


Fig. 13 Root yield as influenced by the effect of row zone and inter row zone management practices

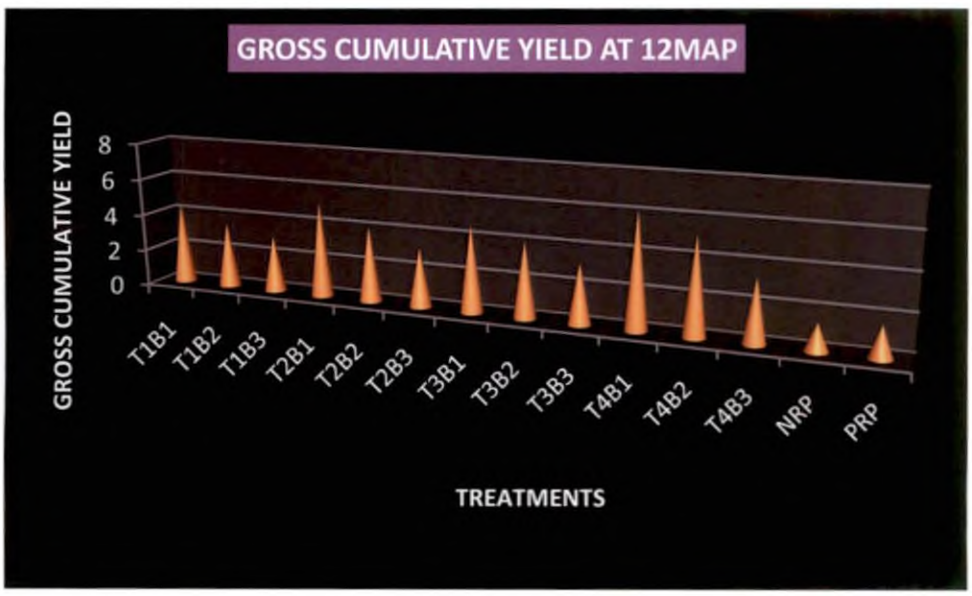


Fig. 14 Effect of treatment combinations on root yield

in situ composting and *in situ* live mulch (concurrent production – vetiver prunings – of mulch as in intercropping) and stubbles and residues from broad beds were used for stubble mulching. Mulch is strategically located at soil- atmosphere interface and acts both as soil protector and soil amendment favourably and positively influences soil conservation, soil ecology, vetiver yield and environment.

Mulching alters the entire soil ecology as it has a profound water conserving effect by reducing evaporation losses. Therefore more water is retained in soil profile, where it remains potentially available for crop growth. Mulching also reduces soil temperature oscillations as it has profound effect on soil fertility by maintaining the fertile top soil *in situ* and adding to the stock of organic matter. It also favours the activity of soil biota by providing a readily available food source and creating more favourable soil habitat. The activity of soil biota contributes to improved soil, physical and chemical properties.

Mulching tends to stabilize and enhance vetiver yield – particularly when it directly alleviates constraints for crop growth (water and nutrient availability). It also implies more water infiltration and carbon sequestration through temporary immobilization of carbon di oxide, there by potentially converting mulch from a net source to a net sink carbon di oxide (Erenstin, 2003).

Vetiver leaves are excellent material for mulching as they are durable and long lasting. Silica content of vetiver leaf mass is quite high hence it takes longer time for decomposition. This makes vetiver leaves ideal for use as a mulch material.

Vetiver leaves and culms are completely decomposed to become soft, disintegrated and dark brown to black in colour. Vetiver compost contains major nutrients from the decomposition process, N, P, K and Ca with a p^H of 7.0. In addition vetiver compost also provides humic acid for enhancing soil activity. In addition vetiver leaves and culms are also used for the preparation of nursery blocks and planting medium (Panichpol *et al*., 1996).

Root developemnt in vetiver (T4B1)

Root developemnt in vetiver (T3B1)

Root developemnt in vetiver (T4B2)

Plate.7 Treatment combinations on root yield of vetiver

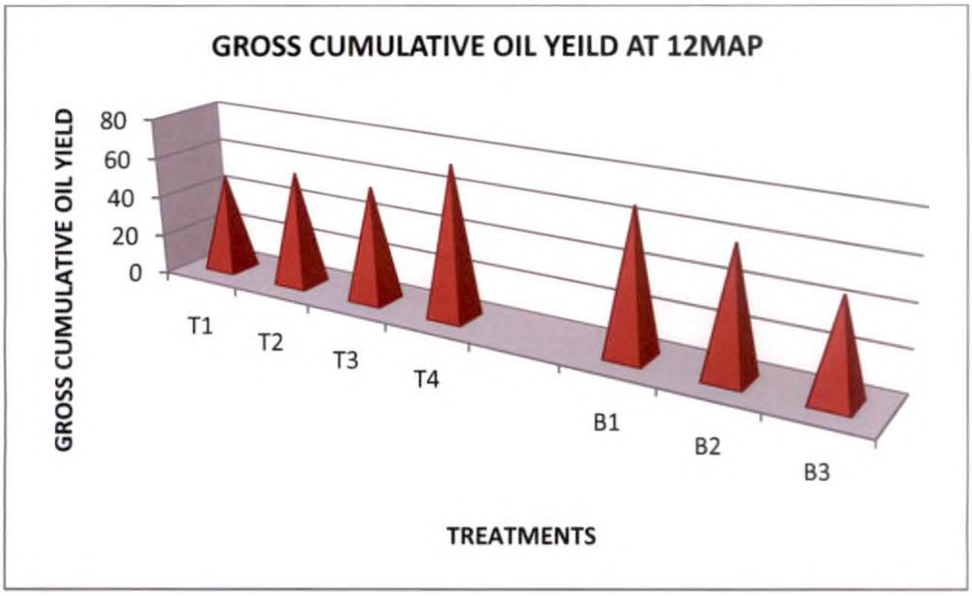


Fig. 15 Oil yield as influenced by the effect of row zone and inter row zone management practices

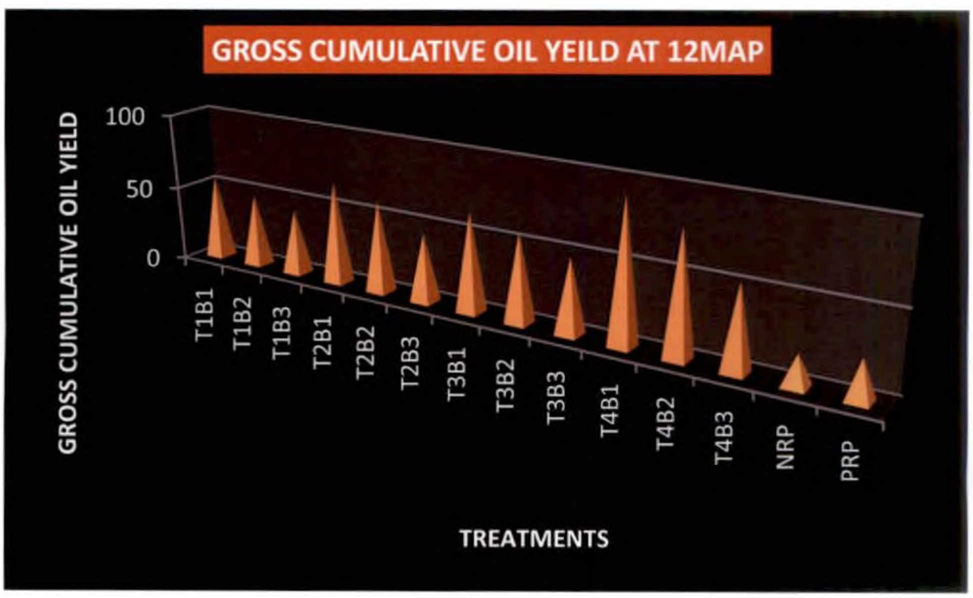


Fig. 16 Effect of treatment combinations on oil yield

Vetiver is the only grass cultivated specifically for its root essential oil. Vetiver root cells produce a few oil precursors, which are then metabolized by root bacteria to build up the complexity of vetiver oil. The bacteria are found in the oil producing cells as well as in root locations that are closely associated with the soil. Vetiver oil is used in plants as pheromones and juvenile hormones. It also contains alcohols and hydrocarbons which together with the sesquiterpene are primarily used in perfumery and cosmetics. The perfumery and flavouring industry could benefit from the increased value of these bacteria.

5.2.7 Content and uptake of NPK

Content and uptake of leaf NPK were influenced by row zone management practices and *in situ* composting + stubble mulching + summer irrigation at 80 mm CPE recorded higher values. Vetiver responded very well to the management practice in enhancing root NPK content and its uptake by the roots. Higher root phosphorus and potassium contents and NPK uptake by roots were recorded when multiple cropping was practiced in broad beds. However, total NPK uptake enhanced when *in situ* composting was carried out followed by stubble mulching and practiced multiple cropping in broad beds. Integration of the above two treatments created favourable conditions for higher total NPK uptake.

Quantitative expression of nutrient uptake is the product of nutrient content in plant tissues and the dry matter production. Addition of vetiver prunings once in four months in multiple cropping resulted in additional incorporation of vetiver leaf biomass which might have enriched soil fertility. Variation in leaf phosphorus uptake was due to difference in phosphorus content and leaf dry matter production (Tables. 14, 19c and Fig 18). The role of potassium in plants is different than that of nitrogen and phosphorus. Being a non-structural element of plant tissues, its function is more in the metabolism of other elements particularly nitrogen and phosphorus. Besides, it is needed for the translocation of other elements within the plant and keeping the

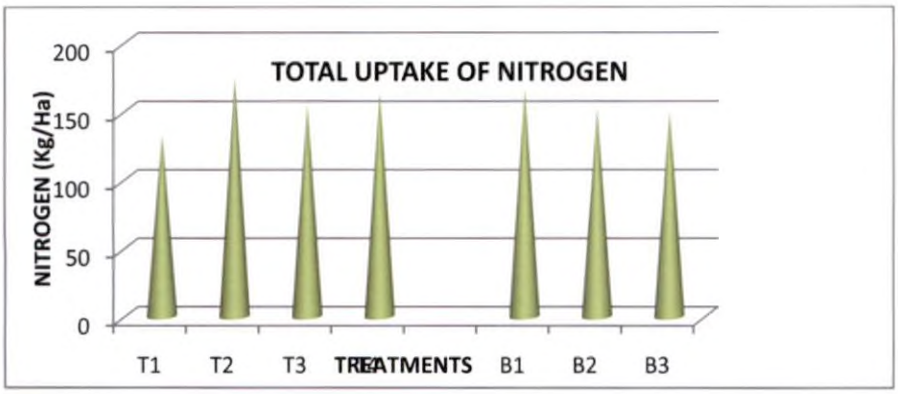


Fig. 17 Nitrogen uptake as influenced by the effect of row zone and inter row zone management practices

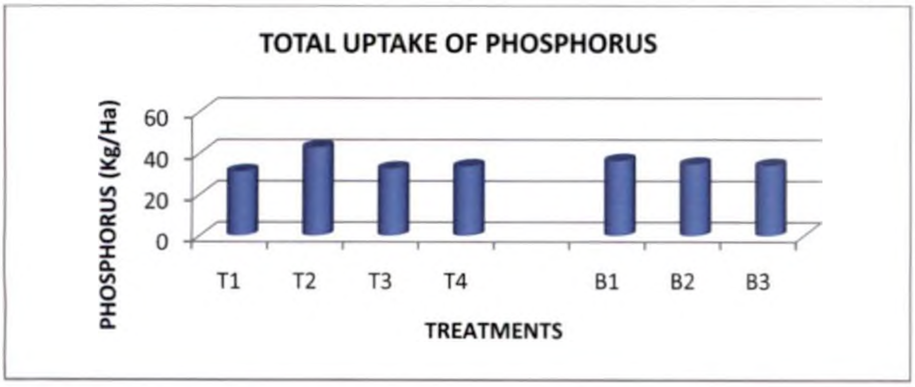


Fig. 18 Phosphorus uptake as influenced by the effect of row zone and inter row zone management practices

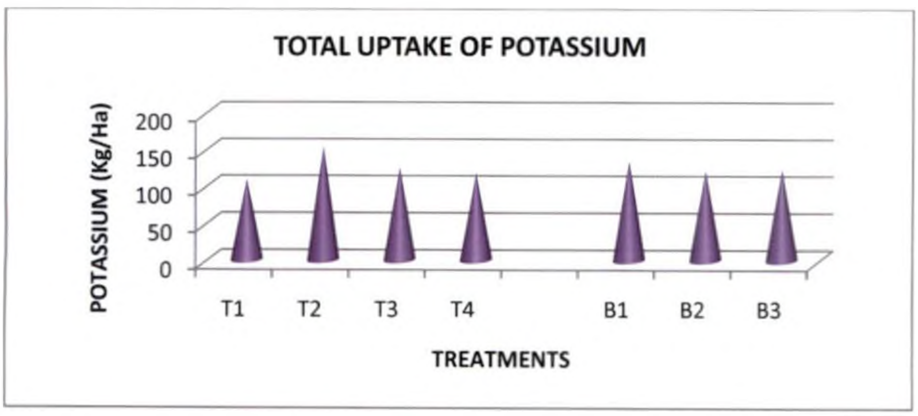


Fig. 19 Potassium uptake as influenced by the effect of row zone and inter row zone management practices

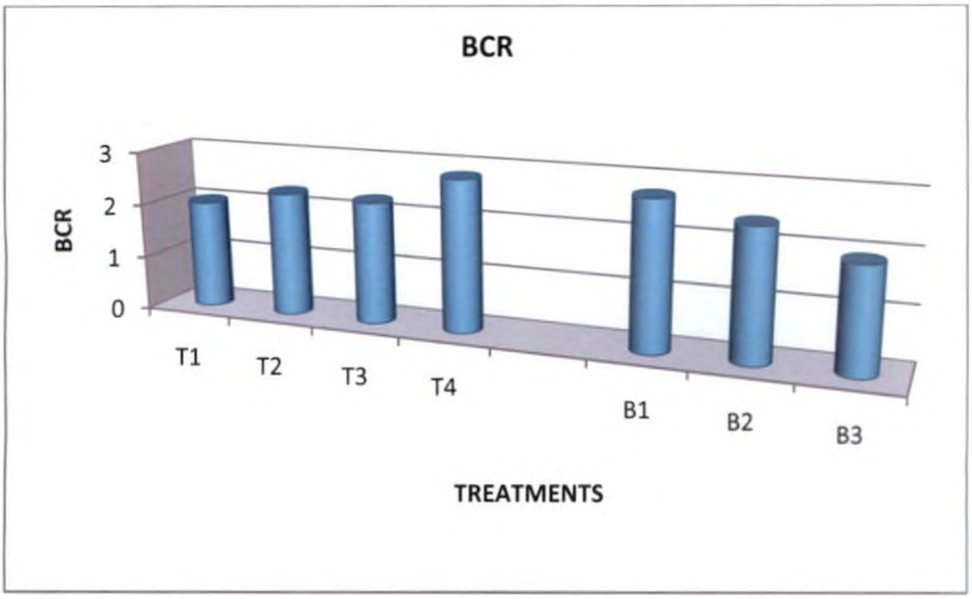


Fig. 20 BCR as influenced by the effects of row zone and inter row zone management practices

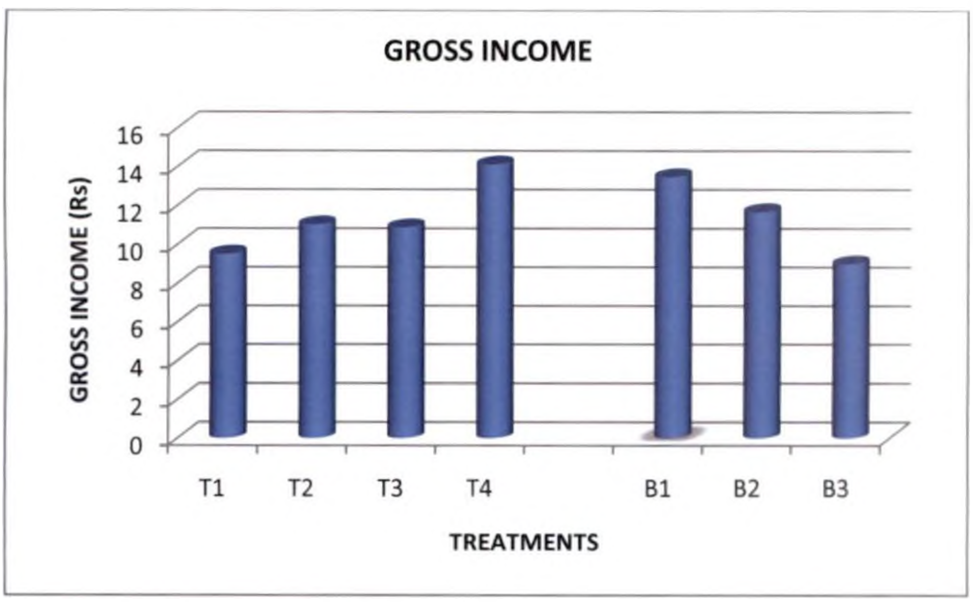


Fig. 21 Gross income as influenced by the effects of row zone and inter row zone management practices

turgidity of plant cells. Whenever, nitrogen and phosphorus are abundantly available in soil, potassium uptake is mandatory in proportion to the available potassium in the soil solution.

5.2.8 Economic analysis

In situ composting recorded the least cost of cultivation as it received less number of irrigations. *In situ* composting + stubble mulching + summer irrigation at 80 mm CPE recorded highest gross income, net income and BCR as it registered the highest root and oil yield. Multiple cropping significantly increased the cost of cultivation as more number of labourers were engaged for pruning and subsequent mulching at four months interval. Gross income, net income and BCR were found to be higher in multiple cropping as it recorded the highest root and oil yield.

Summary

6. SUMMARY

Two experiments were conducted at the Instructional Farm attached to College of Agriculture, Padannakkad to study the effect of single, dual and combined application of microbial inoculants on quality planting material production and to develop eco-friendly techniques to achieve higher root and oil production in vetiver with special reference to climate change mitigation.

Part A: Bioinoculants for quality planting material production

A pot culture trial was laid out in CRD with ten treatments and three replications to study the effect of single, dual, and combined application of Azospirillum, phosphorus solubilising bacteria, arbuscular mycorrhizal fungi and fluorescent pseudomonas on quality planting material production in vetiver.

The effect of bioinoculants on sapling height was evident at all stages of growth and single inoculation with phosphorus solubilising bacteria significantly enhanced sapling height after second and third month of planting. Application of bioinoculants had no significant influence in leaf number after one month of planting.

Significant variations in root parameters were observed at all stages of growth. The effect of single inoculation with phosphorus solubilising bacteria in increasing root number was consistent throughout the nursery period. Dual inoculation with Azospirillum and phosphorus solubilising bacteria drastically reduced root number at second and third month after planting. Contrary to root number, root length was remarkably influenced by dual inoculation with Azospirillum and fluorescent pseudomonas at all stages of growth and it was significantly different from all other treatments compared to uninoculated control.

After one month of planting, Azospirillum which was on par with single inoculation with fluorescent pseudomonas and combined inoculation with

Azospirillum, phosphorus solubilising bacteria, arbuscular mycorrhizal fungi, significantly increased root spread. However, single inoculation with phosphorus solubilising bacteria which was significantly different from all other treatments recorded the highest root spread at second and third month after planting.

Single inoculation with phosphorus solubilising bacteria significantly improved shoot weight throughout the nursery period. A similar trend was observed with respect to root weight and biomass accumulation.

At three month after planting Azospirillum + phosphorus solubilising bacteria + arbuscular mycorrhizal fungi which were on par with dual inoculation with Azospirillum and fluorescent pseudomonas recorded the highest relative leaf water content. The effect of bioinoculants on relative growth rate was not consistant at second and third month after planting.

With respect to root growth potential, the effect of dual inoculation with Azospirillum and fluorescent pseudomonas was pronounced throughout nursery period. Sturdiness quotient also improved consequent to inoculation with phosphorus solubilising bacteria at two and three month after planting. Single inoculation with phosphorus solubilising bacteria significantly enhanced sapling growth potential.

Dual inoculation with Azospirillum and phosphorus solubilising bacteria followed by combined inoculation with Azospirillum, phosphorus solubilising bacteria, arbuscular mycorrhizal fungi and fluorescent pseudomonas significantly enhanced Azospirillum population at three month after planting. Single inoculation with phosphorus solubilising bacteria significantly enhanced the population of rhizosphere phosphorus solubilising bacteria. Single inoculation with arbuscular mycorrhizal fungi was beneficial in significantly enhancing its population. Single inoculation with fluorescent pseudomonas was found favourable in significantly improving its population at three month after planting.

Part B: Multiple cropping and micro site enrichment techniques for row zone and inter-row zone management.

The field experiment in factorial RBD with 12+2 treatment combinations was conducted for one year to develop eco-friendly techniques for higher root and oil production in vetiver. The treatments consisted of combinations of four row zone management practices namely T_1 (*in situ* composting in trenches), T_2 (*in situ* composting in trenches + Stubble mulching), T_3 (*in situ* composting in trenches+ Stubble mulching + Summer irrigation at 40 mm CPE), T_4 (*in situ* composting in trenches+ Stubble mulching + Summer irrigation at 80 mm CPE); and three inter row zone management practices namely B_1 (Multiple cropping), B_2 (Double cropping), B_3 (Mono cropping) besides two control treatments namely sole cropping 1 (Normal Row Planting), sole cropping 2 (Paired Row Planting).

Row zone management and inter row zone management practices and their interactions didn't significantly influence plant height at four, eight and twelve month after planting. *In situ* composting in trenches+ Stubble mulching + summer irrigation at 40 mm CPE registered the highest leaf number at four months after planting.

In situ composting in trenches followed by stubble mulching; and multiple cropping and their interaction recorded the highest tiller production at twelve month after planting.

At twelve months after planting *in situ* composting in trenches + Stubble mulching recorded the highest root number and root length. Though inter row zone management practices had no significant influence on root length multiple cropping showed greater length of roots throughout the growth period. *In situ* composting in trenches and multiple cropping and their interaction effects significantly enhanced root weight at all stages of growth.

Integration of *in situ* composting in trenches + stubble mulching; and multiple cropping registered higher relative leaf water content. Relative leaf water content was not at all significantly influenced by planting patterns.

Between treatments including control, the effect was appreciable at twelve month after planting alone and the treatment combination *in situ* composting in trenches + stubble mulching and multiple cropping showed greater chlorophyll contents.

In situ composting in trenches + stubble mulching + summer irrigation at 80 mm CPE; and multiple cropping and their interactions were found superior in enhancing root yield, root productivity and oil yield.

In situ composting in trenches recorded the least cost of cultivation. The highest cost of cultivation was registered by *in situ* composting in trenches + stubble mulching + summer irrigation at 80 mm CPE. This again recorded higher gross income, net income, and BCR. Multiple cropping significantly increased the cost of cultivation. Multiple cropping enhanced gross income, net income and BCR.

Method of planting was also found to exert significant influence on all economic parameters studied and though cost of cultivation was higher for paired row planting, it registered significantly higher gross income, net income and BCR.

In general, *in situ* composting in trenches + Stubble mulching; and multiple cropping enhanced higher leaf dry matter production. Row zone and inter row zone management practices and their interactions significantly influenced root dry matter production at various stages of growth. T_4 at twelve month after planting registered significantly higher root dry matter production. In general the effect of inter row zone management practices was consistent throughout crop growth and B_1 at all stages recorded significantly higher root dry matter production. Integration of *in situ* composting in trenches + Stubble mulching + Summer irrigation at 80 mm CPE; and multiple cropping and their interaction increased root dry matter production and total dry matter production.

Integration of *in situ* composting in trenches + Stubble mulching + Summer irrigation at 80 mm CPE; and multiple cropping resulted in higher concentration of nitrogen, phosphorus and potassium in vetiver leaves and roots.

Integration of *in situ* composting in trenches + Stubble mulching; and multiple cropping was effective in enhancing total plant uptake of nitrogen, phosphorus and potassium.

Significant effect of treatment combination including control was evident on soil moisture. Integration of *in situ* composting in trenches + Stubble mulching + Summer irrigation at 80 mm CPE and double cropping before irrigation and integration of *in situ* composting in trenches + Stubble mulching + Summer irrigation at 80 mm CPE and multiple cropping after irrigation retained higher moisture in the soil.

Seasonal consumptive use, mean daily consumptive use and crop coefficient were not at all influenced by row zone and inter row zone management practices and their interactions.

Crop water use efficiency, field water use efficiency and water productivity were remarkably influenced by row zone and inter row zone management practices and their interactions.

The highest crop water use efficiency and field water use efficiency were achieved consequent to integration of in *situ* composting in trenches + Stubble mulching + Summer irrigation at 80 mm CPE; and multiple cropping. Integration of in *situ* composting in trenches + Stubble mulching; and multiple cropping was found beneficial for achieving higher water productivity.

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*Originals not seen

MULTIPLE CROPPING AND MICROSITE ENRICHMENT IN VETIVER
(*Chrysopogon zizanioides* (L.) Nash

by

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Abstract of the

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ABSTRACT

Vetiver (*Chrysopogon zizanioides*) is the only grass extensively cultivated specifically for its root essential oil, a complex mixture of sesquiterpene alcohols and hydrocarbons. The World Bank has promoted the Vetiver System (VS) since the 1980s for various applications. However, cost effective techniques for increasing root production in the humid tropics are lacking. Two separate experiments were conducted at the Instructional Farm attached to the College of Agriculture, Padannakkad during 2011-13.

PART A. Bio inoculants for Quality Planting Material Production

The trial was conducted for three months to study the effect of single, dual and combined application of microbial inoculants on quality planting material production in vetiver. The ten treatments of the trial laid out in CRD were B_1-Single inoculation with *Azospirillum*, B_2-Single inoculation with PSB, B_3-Single inoculation with AMF, B_4-Single inoculation with Fluorescent Pseudomonads (FP), B_5-Dual inoculation with Azospirillum and PSB, B_6-Dual inoculation with Azospirillum and AMF, B_7-Dual inoculation with Azospirillum and FP, B_8-Combined inoculation with Azospirillum, PSB and AMF, B_9-Combined inoculation with Azospirillum, PSB, AMF and FP and B_{10}-Control (No inoculation).

Single, dual and combined inoculation of bioinoculants influenced sapling growth and vigour in different ways. In general, PSB favourably and significantly influenced sapling height, root number, root spread, shoot weight, root weight, total biomass accumulation, relative leaf water content, sturdiness quotient and sapling growth potential. Significant and positive influence of dual inoculation with Azospirillum and fluorescent pseudomonas was evident on length of root, root growth potential and Azospirillum population.

Part B: Multiple cropping and micro site enrichment techniques for row zone and inter-row zone management

The objective of this experiment was to develop eco-friendly techniques to achieve higher root and oil production in vetiver with special reference to climate change mitigation. The field experiment in factorial RBD with 12+2 treatment combinations was conducted for one year. The treatments consisted of combinations of four row zone management practices namely T_1 (*in situ* composting in trenches), T_2 (*in situ* composting in trenches + stubble mulching), T_3 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 40 mm CPE), T_4 (*in situ* composting in trenches+ stubble mulching + summer irrigation at 80 mm CPE); and three inter row zone management practices namely B_1 (multiple cropping), B_2 (double cropping), B_3 (Mono cropping), besides two control treatments namely S1 : sole cropping - Normal row planting and S2 : sole cropping - Paired row planting.

The effect of row zone and inter row zone management practices and their interactions were inconsistent in significantly influencing various morphological characters and root parameters of vetiver during different stages of its growth. However, positive and significant influence of row zone and inter row zone management practices and their interactions benefitted vetiver in improving root production and productivity besides, improvement in oil yield. Integration of *in situ* composting in trenches + stubble mulching; and multiple cropping was effective in enhancing total plant uptake of nitrogen, phosphorus and potassium.

Seasonal consumptive use, mean daily consumptive use and crop coefficient were not at all influenced by row zone and inter row zone management practices and their interactions. The highest crop water use efficiency, field water use efficiency, higher gross income, net income, and BCR were recorded consequent to integration of *in situ* composting in trenches + stubble mulching + summer irrigation at 80 mm CPE; and multiple cropping.

Appendix

Appendix I

Weather data during the crop period

Period	Maximum temperature (^0C)	Minimum temperature (^0C)	Rainfall (mm)	Relative humidity (%)	Evaporation (mm)
April	34.6	25.6	22.3	76.3	4.9
May	32.8	23.9	86.8	72.7	4.5
June	30.3	23.2	904.9	86.8	2.3
July	30.0	23.0	471.6	88.8	2.7
August	29.2	22.6	856.1	89.3	2.4
September	30.4	22.7	352.5	81.1	3.2
October	31.8	23.2	128.8	78.1	3.8
November	31.0	21.7	77.5	74.7	3.1
December	32.7	20.7	0.00	71.6	3.5
January	32.7	20.0	0.00	73.5	3.5
February	33.3	22.0	21.1	74.1	4.2
March	33.9	23.5	3.2	74.7	4.9