RESOURCE MANAGEMENT FOR SOURCE – SINK MODULATION IN CHINESE POTATO [*Plectranthus rotundifolius* (Poir.) Spreng.]

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by

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THESIS
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DEPARTMENT OF AGRONOMY
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KERALA, INDIA
2021

DECLARATION

I, hereby declare that this thesis entitled **“Resource management for source – sink modulation in Chinese potato [*Plectranthus rotundifolius* (Poir.) Spreng.]”** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
BA	Benzyl adenine
BCR	Benefit cost ratio
C	Carbon
CD	Critical difference
cfu g^{-1}	colony forming unit per gram
CGR	Crop Growth Rate
Cm	centimeter
C: N ratio	Carbon to nitrogen ratio
CO_2	Carbon dioxide
DAP	Days after planting
day^{-1}	Per day
DMP	Dry matter production
EC	Electrical conductivity
eCO_2	Elevated carbon dioxide
et al.	Co –workers/co-authors
Fig	Figure
FYM	Farmyard manure
g	gram
g cm^{-2} day^{-1}	gram per square centimetre per day

g g^{-1} day^{-1}	gram per gram per day
g m^{-2} day^{-1}	gram per square metre per day
g L^{-1}	gram per litre
ha^{-1}	per hectare
HA	Humic acid
HI	Harvest index
ICAR	Indian Council of Agricultural Research
K	Potassium
KAU	Kerala Agricultural University
kg	kilogram
kg ha^{-1}	kilogram per hectare
LAI	Leaf area index
L^{-1}	per litre
MSL	Mean Sea Level
M	metre
m^2	square metre
mg L^{-1}	milligram per litre
mL	milliliter
µg TPF g^{-1} soil 24 hr^{-1}	microgram of triphenyl formazan (TPF) formed per gram of soil per 24 hours
N	Nitrogen

NAR	Net Assimilation Rate
NS	Not significant
P	Phosphorus
pH	Negative logarithm of H^+ ion concentration
PGPR	Plant Growth Promoting Rhizobacteria
ppm	parts per million
RGR	Relative growth rate
RH	Relative humidity
SEm±	Standard error of means
t	tonnes
t ha^{-1}	tonnes per hectare
TTC	Triphenyl Tetrazolium Chloride
var.	variety
viz.	namely
vs	versus

LIST OF SYMBOLS

@	At the rate of
®	Registered sign
™	Trade mark sign
° C	Degree Celsius
/	Or
° E	Degree east
° N	Degree north
%	Per cent
±	Plus-minus sign
₹	Rupees

INTRODUCTION

1. INTRODUCTION

Tuber crops, acclaimed for their resilience and high biological efficiency have gained priority in sustainable production systems in recent years in wake of the climate change impacts on agriculture. During the past two years, the entire world has been swirled into a new catastrophe, the coronavirus disease (COVID -19) pandemic. The restrictions imposed on the movement of people and goods impaired access to commodities, markets, services and food and these had an instant effect, especially on food systems in developing countries. The crisis of food and nutritional security exacerbated on one hand, and on the other, malnutrition succumbed the weaker sections to the fatality. The unaffordability of healthy and nutrient adequate diets and the break-in supply chains of food have urged the focus on nutritious and crisis-responsive crops, the tuber crops (Heck *et al.*, 2020).

Chinese potato [*Plectranthus rotundifolius* (Poir.) Spreng.] also known as coleus, hausa potato and country potato, is a minor tuber crop cultivated in many parts of the world for its edible tubers. The crop combines the typical characters of vegetable and staple food crops: high mineral and vitamin content, excellent protein quality, and good energy value. Chinese potato is also reckoned to be medicinally important due to the presence of flavonoids and enzyme inhibitors. Tubers of Chinese potato elicit an aromatic flavour and a delicious taste on cooking which gives it a unique status and consumer preference among tropical tubers.

On a global scale, Chinese potato is the most widespread of the cultivated species in the Lamiaceae (Labiatae) family of order Lamiales, and is believed to be of more economic importance in tropical Asia particularly in India, Sri Lanka, Madagascar, Malaysia, Indonesia, and southern Thailand. In India, the crop is cultivated in Kerala, Karnataka, and the Tirunelveli district of Tamil Nadu. Statistical data on the area under cultivation in Kerala, revealed that it has declined drastically in the past decade, from 1424 ha to 993 ha (GoK, 2011; 2021), by nearly 30.26 per cent.

The high biological efficiency and short duration (5 months) of the crop offer ample scope for its inclusion in cropping systems for enhancing productivity. Chinese potato with its high nutritional quality, has the potential to supplement the food bank, solving problems of malnutrition and improving food and nutritional security. Nevertheless, despite a high production potential, the relatively higher proportion of small-sized tubers in the harvested produce is regarded a negative characteristic and an unappealing trait among the farmers.

Opaleye *et al.* (2018) opined that the crop is limited by a lack of balance between the source and sink capacities which often has led to low marketable yields in the cultivated varieties. A wide genetic diversity exists in Chinese potato in terms of high heritability for tuber yield, harvest index, biological yield per plant, and tuber weight (Murugesan *et al*., 2020).

Adoption of proper management strategies in cultivation can result in higher yields and also favourably influence the size of tubers. Crop yield is linked to photosynthetic efficiency and partitioning of photo-assimilates to the economic parts. Modifying the source capacity in terms of leaf area and higher photosynthetic efficiency by manipulating planting geometry and nutrient management, ensuring better translocation to sink with the use of growth promoters, and enhancing the sink capacity by appropriate land preparation methods are expected to have an impact on the productivity of the Chinese potato.

Land configuration and planting geometry are never outmoded agro-techniques in tuber crops as the favourable niche for tuber development is governed by the soil properties and root growth. Tropical tuber crops are highly nutrient demanding (John *et al*., 2016) and appropriate input management through different approaches can help in achieving the yield potential. Balanced nutrition and enhanced nutrient use efficiency can be ensured with integrated nutrient management and the inclusion of beneficial microorganisms like plant growth promoting rhizobacteria (PGPR) in the nutrient schedule. Exogenously applied plant growth regulators have a significant role in plant developmental and yield governing processes (Peng *et al*., 2012). A coherent strategy for enhanced source-sink efficiency involving nutrient inputs, PGPR, and growth regulators can modulate growth and yield performance in Chinese potato, but concerted research works in this regard are meagre.

Carbon dioxide (CO_2) is an essential environmental resource required as a raw material for the orderly development of all green plants, but the responses of plants to increased concentrations of CO_2 in the atmosphere vary. According to Sicher and Bunce (1999), plant species that have good coordination between source and sink organs, higher transport capacity, and larger sinks can utilize the extra carbon into growth under elevated CO_2 (eCO_2). Photosynthetic regulation partly depends on the balance between the substrate for photosynthesis $CO_{2,}$ and the sink capacity. Tuber crops have high sink capacities and are prophesied to respond positively to eCO_2. However, documented literature, especially in Chinese potato, is not plenty, almost nil.

The research work entitled "Resource management for source-sink modulation in Chinese potato [*Plectranthus rotundifolius* (Poir.) Spreng.]" was hence envisaged with the following objectives:

- To study the influence of planting methods, nutrient management practices, and growth promoters on the source-sink relationship, tuber yield and quality
- To assess the growth and yield responses of the crop to CO_2 fertilization and
- To work out the economics in Chinese potato

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Chinese potato [*Plectranthus rotundifolius* (Poir.) Spreng.] cultivation is often constrained by the small size of tubers that affects marketability, but has huge potential among tuber crops on account of its short duration nature and suitability for inclusion in different sequential cropping systems. The low yields, in addition to the genetic character, can be due to a lack of balance between the source potential and sink capacity which can be modulated by proper resource management techniques. In this background, a research work on the strategies for modulation of source and sink relation in Chinese potato [*Plectranthus rotundifolius* (Poir.) Spreng.] was attempted. Literature pertaining to the different practices including methods of planting, nutrient management and growth promoters and enhanced level of CO_2 on the productivity of Chinese potato are reviewed in this chapter. Wherever information is lacking, pertinent literature on other tuber crops are included.

2.1 RESOURCE MANAGEMENT FOR SOURCE SINK MODULATION

Proper management of resources can result in increased production in crop plants. The response of coleus to improved production technologies has been illustrated (Jayapal, 2012; Opaleye *et al*., 2018). Attempts on the resource management strategies for enhanced yield have been reported by many researchers *viz*., land configuration (Robinson, 1999), planting material (Isaac *et al*., 2015; Nedunchezhiyan *et al*., 2015), spacing (Singels and Smit, 2002), growth regulators (Peleg *et al*., 2011), nutrients (Li *et al*., 2016) and water management (Pushpalatha *et al*., 2020). Carbon dioxide plays an important part in vital plant processes prominently, photosynthesis and respiration.

The higher photosynthetic rate, increased growth and increased productivity under eCO_2 (Miglietta *et al*., 1998) can also contribute to source-sink modulation.

2.1.1 Method of Planting

Proper land preparation and method of planting are imperative factors for higher production and warrant fairness to plants for their survival and efficient use of inputs. The basic purposes of seedbed preparation in tuber crops are to increase rooting depth, improve soil-water management and improve infiltration so as to enhance tuber bulking and yields (FAO, 2000). The importance of land preparation in tuber crops has been described by several authors (Kothari and Reddy, 2009; Yaseen *et al*., 2013).

Soil tillage is a critical factor affecting soil physical properties, and adoption of proper tillage practices has immense potential for productivity enhancement in tuber crops. The influence of different agro techniques on the growth and yield of tuber crops has been investigated by several authors: tillage and planting methods in cassava (Agbede, 2007; Byju *et al*., 2010), potato (Sharma *et al*., 2014), tannia (Jayapal and Swadija, 2019), plant density and spacing in Chinese potato/ frafra potato (Bharathi *et al*., 2004; Akinpelu *et al*., 2017), potato (Wurr *et al*., 1993; Bussan *et al*., 2007; Sen *et al*., 2014) and sweet potato (Dlamini *et al*., 2021). Sakhubai *et al*. (2020) reported that the different methods of planting specific to root crops provide an optimum space to maximize vegetative growth, which subsequently ensured better interception of solar radiation and resulted in higher yields.

2.1.1.1 Effect of Method of Planting on Growth Attributes

Root and tuber crops respond favourably to intensive tillage, followed by ridging or mounding, as the crops are sensitive to soil compaction, inadequate aeration or poor drainage (Howeler *et al*., 1993). Bharathi *et al*. (2004) recorded significantly taller plants (51.83 cm), plant spread (53.88 cm) and leaves (99.08) in Chinese potato with the wider spacing of 60 cm x 45 cm adopted. They also observed an increased number of branches (6.35) at 60 cm x 30 cm spacing, and the lowest was in 60 cm x 15 cm (6.03).

Effect of method of planting and spacing on the growth of medicinal coleus (*Coleus forskohlii* (Willd) Briq.) was studied by Rao (2005) and observed the tallest plants in ridge and furrow method of planting with rooted cuttings compared to the flat bed with unrooted cuttings and a closer spacing (60 cm x 20 cm) compared to the wider spacing. Nevertheless, higher number of lateral branches per plant was recorded in the flat bed method with wider spacing (60 cm x 45 cm). Among spacing and methods of planting, leaf area was maximum with wider spacing and ridge and furrow method of planting. Similar results of increased plant spread with wider spacing in medicinal coleus were documented by Rao and Reddy (2005). According to Bayorbor and Gumah (2007), reducing the intra-row spacing in Chinese potato from 40 cm to 20 cm failed to induce significant effects on the number of branches per plant.

Agbede (2008) compared tillage practices *viz.*, zero tillage with and without mulch, manual mounding and manual ridging with conventional tillage in cocoyam (*Xanthosoma sagittifolium* (L.) Schott) and found significantly lower plant height and leaf area in conventional tillage whereas the number of leaves was unaffected.

Parwada *et al.* (2011) documented that the vines were longer in sweet potato with decreasing ridge inclination of cuttings. Nedunchezhiyan *et al*. (2012) reported significantly higher vine length in conventional tillage method compared to minimum tillage in sweet potato grown. Studies conducted by Masarirambi *et al*. (2012) revealed a significantly higher leaf area with wider spacing of 90 cm x 45 cm in potato compared to narrower spacings of 90 cm x 30 cm and 90 cm x 15 cm. Plants were taller in potato at wider inter-row spacing of 45 cm (Kumar, D *et al.*, 2012). In medicinal coleus (*Coleus barbatus*), maximum plant height (62.67 cm) was observed with a spacing of 30 cm x 30 cm and the highest leaf area (436.89 cm^2), number of branches (31.75) and plant spread (48.59 cm) with a wider spacing of 60 cm x 45 cm (Dev *et al.*, 2013). Singh (2013) also documented significant variation in plant height with spacing in medicinal coleus.

Plants were significantly taller in potato in the ridge method of planting (Qasim *et al.*, 2013) and had the highest plant spread when planted on wide beds compared to other methods of planting. Sharma *et al*. (2014) ascertained that in potato, plant height, number of shoots and compound leaves per plant were not influenced by method of planting *viz*., flat bed and ridge furrow, whereas wider spacing (30 cm x 10 cm) resulted in taller plants and higher number of compound leaves per plant compared to closer spacing (20 cm x 10 cm). Brobbey (2015) observed no significant influence of seed bed type *viz*., mound and ridge on vine length and ground cover in sweet potato whereas larger leaf size was recorded in mound method. Dumbuya (2015) also recorded no significant effect of mound or ridge tillage method on vine length, number of branches and number of leaves in sweet potato.

Ridge and furrow method of planting was found to be superior over flat bed method in terms of leaf area during all crop growth stages in medicinal coleus (Rao *et al*., 2016). Salam *et al*. (2016) observed increased pseudostem height in elephant foot yam with a closer spacing of 40 cm x 40 cm but a higher canopy spread with wider spacing of 80 cm x 80 cm. Saqib *et al*. (2017) reported that sweet potato plants on ridges developed a larger leaf area as compared to plants on beds. Pepo (2018) noticed a better canopy of sweet potato plants raised under flat planting compared to ridge planting.

2.1.1.2 Effect of Method of Planting on Physiological Parameters

Evaluation of different methods of planting in sweet potato by Wagbara *et al*. (1984) revealed significantly higher values of leaf area index (LAI) in the ridge method of planting than the plants grown under the furrow method (0.99) whereas the influence on dry matter yield remained non significant. An increase in biomass production with a decrease in spacing was observed by Jayalakshmi (2003) in medicinal coleus. Similar results were also reported by Singh (2013) and Mastiholi *et al*. (2013). Rao (2005) observed significant variation in dry weight of coleus roots with spacing. Higher dry weight was observed in 60 cm x

45 cm spacing compared to 60 cm x 30 cm at 120 days after planting (DAP), while the method of planting could not produce marked differences in root dry weight.

Bayorbor and Gumah (2007) recorded higher vine dry matter of frafra potato with an intra row spacing of 40 cm and the highest LAI in closely spaced plants (20 cm). Singh (2013) examined the variations in the physiological traits of *Coleus forskohlii* due to spacing and documented the significant influence on leaf area, dry matter, LAI, Crop growth rate (CGR) and Relative growth rate (RGR). The author reported higher LAI and lower CGR with a closer spacing of 60 cm x 20 cm during 60- 90, 90- 120 and 120- 150 DAP.

Nedunchezhiyan *et al*. (2012) recorded higher LAI in conventional tillage compared to minimum tillage in sweet potato at Orissa. Comparing the land preparation methods in sweet potato, Ahmed *et al*. (2012) recorded increased dry matter of tuberous roots with ridge planting in comparison to flat and sunken beds. Photosynthetic capacity measured in terms of SPAD reading was higher with flat planting compared to ridge and furrow planting in sweet potato (Pepo, 2018).

2.1.1.3 Effect of Method of Planting on Yield Attributes and Yield

The influence of different land preparation methods, pit followed by mound, flat, mound and ridge methods on tuber yield in cassava was explored (CTCRI, 1971) and the results documented revealed comparable yields although the pit followed by mound method recorded a slightly higher yield.

Similar reports on the non significant variations in tuber yields were illustrated in yams (Lal and Hahn, 1977), cassava (Okigbo, 1979) and sweet potato (Wagbara *et al*., 1984). However, Ravindran and Mohankumar (1985) reported maximum yield in sweet potato with mound planting both under upland and lowland situations. The effect of deep and shallow tillage either by tractor ploughing or by manual labour did not show any significant difference in the yield of cassava (George *et al.*, 2000). Janssens (2001) observed planting on mounds to favour formation of tuberous roots better than ridge planting.

In Bangladesh, sweet potato yields were higher in alluvial soils under irrigated conditions in trench planting followed by ridge and flat method of planting (Bhuiyan *et al.*, 2006). Significantly higher length and girth of tubers were observed with broad bed furrow compared to ridge and furrow methods of planting in sweet potato (Nasare *et al.*, 2009). Ahmed *et al.* (2012) observed significantly higher marketable and total fresh tuberous root weight with ridge method in sweet potato compared to flat as well as sunken seedbeds. They also observed statistically similar number of total and marketable tuberous roots.

Nedunchezhiyan *et al.* (2012) recorded significantly higher root diameter, root yield per plant and root yield ha^{-1} with conventional tillage compared to minimum tillage in sweet potato during both the years of experimentation.

The influence of different tillage and planting methods on cassava root yield was studied by Byju *et al.* (2013) and pointed out that the root yield was significantly higher for the treatment with chisel ploughing along with ridge and furrow method of planting (38.67 t ha $^{-1}$).

Nedunchezhiyan *et al.* (2013) reported that method of tillage had significant impact on storage root yield of sweet potato and the conventional tillage produced significantly superior yield attributes, yield and harvest index over minimum tillage.

The ridge method of tillage recorded longer mean storage root length (134.2 mm) in sweet potato than from mounds (115.9 mm), while storage root diameter and yield were comparable (Chagonda *et al.*, 2014). Akinpelu *et al.* (2017) reported that narrowly spaced hausa potato recorded the maximum tuber yield (3.89 t ha^{-1}).

Brobbey (2015) recorded higher number of marketable tubers, marketable tuber weight, total root yield and harvest index in sweet potato with ridge tillage method.

Comparing two tillage methods in sweet potato, Dumbuya (2015) found that the ridge method had the greatest root yields (14.17 t ha^{-1}) and mound, the lowest (11.48 t ha^{-1}). Patel and Patel (2017) observed significant influence of method of planting on tuber yield in greater yam (*Dioscorea alata*) and ridge and furrow method recorded 16.50 and 23.13 per cent higher tuber yield over raised bed and flat bed method of planting respectively.

The superiority of flat method of planting in sweet potato over ridges has been documented. Szarvas *et al*. (2017) observed that the yield of sweet potato was higher in flat planting than in ridge planting.

Jayapal and Swadija (2019) observed significant influence of tillage on yield parameters and yield in tannia and recorded higher cormel number, cormel weight, cormel yield and corm yield in deep tillage followed by mound system compared to conventional tillage followed by mound system. Significantly highest harvest index with deep tillage in tannia was recorded by Jayapal and Swadija (2020).

The influence of spacing on tuber production and yields was investigated and Allen and Wurr (1992) opined that inter and intra-row spacing are the major agronomic parameters which affect grade-wise tuber distribution. Das and Deka (2002) found that average tuber weight, total tuber yield and marketable yield in potato were the highest with a spacing of 50 cm x 20 cm.

Belehu (2003) observed a decrease in storage root number, marketable storage root number, and storage root mass and marketable storage root mass in sweet potato with the decrease in spacing from 50 cm x 40 cm to 50 cm x 20 cm. Higher shoot and root dry weight per hectare were recorded in the closer spacing.

A wider spacing of 60 cm x 45 cm in Chinese potato resulted in significantly higher number of tubers (23.03), marketable tubers (14.4), weight of tuber (253.78 g) and weight of marketable tubers (221.40 g) per plant, while a higher tuber yield (14.94 t ha^{-1}) was realized at the closer spacing of 60 cm x 15 cm (Bharathi *et al*., 2004).

Rao (2005) recorded maximum fresh weight of roots in medicinal coleus with flat bed method of planting compared to ridges and dry root yield, with a closer spacing of 60 cm x 20 cm. Similar results of higher dry tuber (1.57 t ha^{-1}) with closer spacing of 60 cm x 20 in *C. forskohlii* were reported by Mastiholi (2008). In Chinese potato, Bayorbor and Gumah (2007) reported a 14.3 per cent increase in yield with a closer intra row spacing of 20 cm compared to wider intra-row spacing of 40 cm.

Bussan *et al*. (2007) documented a reduction in average tuber size and increase in yield with decreased spacing in potato. Similar reports were documented by several authors in tuber crops (Kumar *et al*., 2009; Aminifard *et al*., 2012; Dev *et al*., 2013).

Salam *et al*. (2016) observed significantly higher weight of corm with wider spacing 80 cm x 80 cm and corm yield per unit area with closer spacing of 40 cm x 40 cm in elephant foot yam.

Influence of planting methods and spacing on potato minituber production was studied by Sharma *et al*. (2014) and among methods of planting, flat bed method of planting resulted in significantly higher number (232.6 m^{-2}) and yield of mini-tubers (2.23 kg m^{-2}) as well as large sized mini-tubers (> 20g) over the ridge furrow method and higher number of mini-tubers (237.7 m^{-2}) at a closer spacing (20 x 10 cm) but not the yields over the wider (30 x 10 cm) spacing, whereas higher proportions of large-size mini-tubers were recorded in the wider spacing of 30 cm x 10 cm.

Pepo (2018) observed a significantly higher marketable tuber yield and a lesser proportion of non-marketable tubers in sweet potato raised under flat planting compared to ridge planting. The study also revealed a significantly higher yield with flat bed planting at a closer row spacing of 0.75 m compared to flat planting of 1.0 m between rows and ridge planting (0.75 m x 1.0 m between rows).

2.1.1.4 Effect of Method of Planting on Nutrient Uptake and Quality

Tillage had a significant influence on nutrient content in cocoyam (Agbede, 2008) and higher leaf NPK content were evinced in plants grown on mounds and ridges. Byju *et al*. (2010) recorded higher N uptake (213.44 kg ha^{-1}) and K uptake (185.33 kg ha^{-1}) in cassava with chisel ploughing followed by ridge and furrow. Higher N uptake of cassava was noticed in treatments containing ridge and furrow method of planting compared to flat bed and farmers practice (Byju *et al*., 2013).

Significantly higher uptake of N (117.3 kg ha^{-1}), P (14.4 kg ha^{-1}) and K (112.2 kg ha^{-1}) was recorded with conventional tillage than minimum tillage in sweet potato (Nedunchezhiyan *et al*., 2013).

The N and K content in potato tuber were markedly different in potato due to different methods of planting (Singh *et al*., 2016). They noticed significantly higher N (42.33 kg ha^{-1}) and K uptake of 93.52 kg ha^{-1}) under ridge and furrow method of planting compared to flat bed and paired ridge row methods.

Closer spacing of 60 cm x 20 cm recorded significantly higher nutrient uptake (21.6, 2.6 and 25.3 kg ha^{-1} of N, P and K respectively) in tubers of medicinal coleus (Mastiholi *et al*., 2013). Dev *et al*. (2013) observed the decrease in quality (essential oil yield) with decrease in spacing from 60 cm x 45 cm to 30 cm x 30 cm. Closer spacing of 60 cm x 20 cm resulted in lower N content (0.52 %) and protein (3.56 %) in *C. forskohlii* (Singh, 2013).

The tropical tuber crops are underground storage organs that accumulate starch (More *et al*., 2019). Coleus starch is reported to have high amylose content (Moorthy, 2002) and the total content in tubers may be affected by management practices. The influence of spacing has also been illustrated by Essah *et al*. (2004) in potato.

Starch, protein and total sugar contents including sucrose, glucose and fructose of tuber unaffected by tillage in sweet potato (Dumbuya, 2015). Brobbey (2015) recorded significantly higher protein content (6.43 mg 100 g^{-1}) in mound planted sweet potato compared to those on ridge seedbed while starch content in the roots from the ridges (68.13 mg 100 g^{-1}) was significantly higher than that from the mounds. The root sucrose content remained comparable. Similarly in the studies conducted by Pepo (2019), starch and protein content of tubers with flat and ridge planting methods in sweet potato were on par. However, Jayapal and Swadija (2020) assessed higher starch (73.09 %) and protein (7.53 %) in tannia with deep tillage.

2.1.1.5 Effect of Method of Planting on Soil Properties

Planting patterns have distinctive effects on the soil micro-ecological environment and soil quality (Qin *et al*., 2016). Agbede (2008) observed that soil chemical properties like organic carbon, N, P and K content were significantly influenced by tillage operations in cocoyam wherein zero tillage with and without mulch, manual mounding and manual ridging recorded significantly higher organic carbon, N and K contents during both the years of study and P during the second year.

According to Agbede and Adekiya (2009), tilled plots (manual mounding, manual ridging, row tillage and conventional tillage) resulted in higher soil N, P, K compared with untilled (manual clearing) plot of sweet potato. They also recorded higher bulk density and lower porosity in the manually cleared soil while the highest porosity was recorded in the conventionally tilled plots.

Byju *et al.* (2010) observed significantly higher available K with chisel and disc ploughing compared to farmers practice in cassava. It was also recorded that there was a more uniform distribution of plant available forms of N and K in the plots where chisel ploughing was followed by ridge and furrow method of planting. Singh *et al*. (2016) also reported significantly superior organic carbon in soil for ridge and furrow method of planting (2.13 %) compared to flat bed method (2.04 %) and lower available P was noted in the latter. Soil pH, available N and K were could not be observed with any of the methods of planting treatments in potato.

2.1.1.6 Effect of Method of Planting on Economics

Gross returns, net returns and benefit: cost ratio, ₹116580 ha^{-1}, ₹ 76260 ha^{-1} and 2.89 were higher in conventional tillage than minimum tillage in sweet potato (Nedunchezhiyan *et al.*, 2013). Tillage method showed significant difference in economics of cultivation in sweet potato and tillage with ridging had the highest benefit value and mounding had the lowest benefit value (Dumbuya, 2015). Ridge and furrow recorded higher net returns and benefit cost ratio values of ₹ 293933 ha^{-1} and 2.42 were reported in greater yam compared to flat bed and raised bed planting methods (Patel and Patel, 2017).

Inter and intra row spacing and the resulting plant population have direct influence on net returns in potato (Love and Johns, 1999). A wider spacing was found to be profitable in potato (Kumar *et al.*, 2011) and comum tannia [*Xanthosoma mafaffa* (L.) Schott] (Gassi *et al.*, 2014).

2.1.2 Nutrient Management

Tropical tuber crops respond well to the application of manures and fertilizers (John *et al.*, 2005). The high productivity entails a higher nutrient uptake and hence removal from soil. Desai and Thirumala (2014) opined that nutrient management plays an important role in enhancing productivity in coleus. A balanced and integrated nutrient management strategy comprising of nutrients from different sources can satisfy the high nutrient requirement of the crops and help in achieving the yield potential (John *et al*., 2016).

Nitrogen (N), one of the vital macronutrients for growth and biomass production is a component of chlorophyll, amino acids, proteins, nucleic acids, coenzymes and membrane constituents (Andrews *et al*., 2013; Ahmed *et al*., 2015).

The necessity of phosphorus (P) as a plant nutrient is emphasized, it being an essential constituent of many organic compounds that are very important for metabolic processes and root development. It is involved in synthesis of adenosine triphosphate (ATP), formation of ribonucleic acid (RNA) and phospholipids (Purekar *et al*., 1992). Phosphorus can increase the size and percentage of dry matter in the tubers (Rosen *et al*., 2014).

Potassium (K) is regarded as a key nutrient input in tuber crops with respect to yield and quality. The nutrient plays a pivotal role in cellular activities such as enzyme activation and stomata movement, ATP generation, photosynthesis and translocation of carbohydrates thus favouring plant growth, dry matter partitioning and production of tuberous roots hence better bulking for higher tuber weight (Suja *et al*., 2010; Chua *et al*., 2020). Potassium protects against drought and reduce the incidence of pest in tuber crops (Singh *et al*., 2020).

2.1.2.1 Effect of Nutrient Management on Growth Attributes

A fertilizer dose of 80:60:80 kg NPK ha^{-1} was suggested by Rajmohan and Sethumadhavan (1980) in coleus with full dose of P and half dose of N and K at the time of planting and the remaining dose, six weeks after planting. Integrated nutrient management in Chinese potato was explored by Archana (2001) and the dose of 60 kg P_2O_5 ha^{-1} gave comparable yields as 30 kg P_2O_5 ha^{-1} with respect to the growth characters.

In the studies conducted at CTCRI, application of N at 100 kg ha^{-1} in Chinese potato produced significantly taller plants at 45 DAP (Nair and Mohandas, 2004). They also observed that potash application at 75 kg ha^{-1} profoundly influenced plant height at 45 DAP and number of leaves at 15 DAP, but the effect on the number of leaves per plant at 30 and 45 DAP was non-significant. According to Nair and Mohandas (2005), the different levels of N and K tried failed to induce significant variations in plant height and number of leaves at all the stages of observation.

The recommendations of KAU (2016) comprise a nutrient dose of 60:60:100 kg NPK ha^{-1} along with 10 t of FYM. Nutrient management for offseason production of coleus was investigated by Anju *et al.* (2016) and the modified nutrient dose of 60:30:120 kg NPK ha^{-1} through fertilizers produced the tallest plants, the highest number of branches per plant and number of leaves at the different stages of observations.

2.1.2.2 Effect of Nutrient Management on Physiological Parameters

Leaf Area Index, dry matter production (DMP) and RGR in coleus were not significantly influenced by nutrient doses of 60:30:100 and 60:60:100 kg NPK ha^{-1} whereas higher values of CGR and Net Assimilation Rate (NAR) were registered during 120 DAP to harvest in 60:30:100 kg NPK ha^{-1} (Archana, 2001). In sweet potato, application of 60:40:60 kg NPK ha^{-1} and planting at a spacing of 60 cm x 30 cm resulted in the significantly highest chlorophyll stability index (Sahoo *et al*., 2013). Application of 75 per cent of recommended dose of nutrients (RDN) through chemical fertilizers and 25 per cent through FYM or 100 per cent RDN through chemical fertilizers enhanced LAI and dry matter accumulation in potato cultivar Kufri Megha (Baishya *et al*., 2013).

Anju *et al*. (2016) observed the highest LAI in Chinese potato and higher DMP at harvest (5.59 t ha^{-1}) with the application of the NPK dose of 60:30:120 kg ha^{-1}. Organic nutrition in cassava could generate comparatively higher dry matter (Radhakrishnan and Suja, 2017). Absolute growth rate (AGR) and CGR in potato were maximum during 60 DAP to maturity stage, with 75 per cent recommended dose of fertilizers and 25 per cent N applied through FYM (Sharma *et al*., 2019). Improved biomass partitioning to tubers under organic management in Chinese potato was reported by Suja *et al*. (2021).

2.1.2.3 Effect of Nutrient Management on Yield Attributes and Yield

Rajmohan and Sethumadhavan (1980) noticed significant increase in tuber yield in coleus when the N dose was increased from 40 to 80 kg ha^{-1}. Investigations on the standardisation of nutrient dose recommend 60, 60 and 100 kg of N, P_2O_5 and K_2O ha^{-1} along with FYM @ 10 t ha^{-1} as the ideal dose in coleus (Kumar *et al*., 2000).

Archana (2001) documented that the yield components in coleus were not influenced by increased rate of P application (60 kg ha^{-1}) when applied with a uniform dose of 60 kg N ha^{-1} and 100 kg K_2O ha^{-1}. However, the integrated application of organic manures, fertilizers and biofertilizers could significantly improve the productivity of coleus.

Agronomic investigation on the response of coleus to varying N levels recorded a maximum tuber yield of 9.55 t ha^{-1} with 75 kg N ha^{-1} which was on par with 100 kg N ha^{-1} whereas number of tubers per plant were comparable (Nair and Mohandas, 2004). Further studies (Nair and Mohandas, 2005) revealed application of 100 N kg ha^{-1} to yield the highest number of tubers per plant (17.00) and tuber yield (12.48 t ha^{-1}). The studies also revealed the significant influence of K @ 75 kg ha^{-1} on the mean tuber weight.

Application of the recommended basal dose of FYM @ 10 t ha^{-1} and 100 per cent of NPK (60:60:100 kg ha^{-1}) through organic manures (FYM @ 6 t ha^{-1} + coir pith compost @ 3 t ha^{-1} + wood ash @ 3 t ha^{-1}) along with PGPR Mix 1 was necessary for getting higher yields under organic production of Chinese potato (Jayapal *et al*., 2013).

Anju (2014) observed significantly higher yield attributes per plant, number of tubers (11.53), number of marketable tubers (6.94) and percentage marketable tubers (59.88), weight of marketable tubers (81.56 g) percentage weight of marketable tubers (89.26%) and tuber weight (91.9 g), with nutrient dose of 60:30:120 kg NPK ha^{-1} in Chinese potato, variety Suphala. Tuber yields were also maximum (14.36 t ha^{-1}) at this dose compared to the recommended dose of 60:60:100 kg NPK ha^{-1}.

John *et al.* (2016) in their review stated that the best soil pH for good growth and tuber production in Chinese potato is 6.6–7.0. Farmyard Manure @ 4.5 t ha^{-1} along with wood ash @ 1.1–2.2 tha^{-1} and a fertilizer dose of N, $P_2 O_5$ and $K_2 O$ @ 80, 60 and 80 kg ha^{-1} was suggested for optimum yields.

2.1.2.4 Effect of Nutrient Management on Nutrient Uptake and Quality

A crop of coleus yielding 25.7 t ha^{-1} of tuber removed 106.7, 13.2 and 107.4 kg NPK ha^{-1} (Kabeerathumma *et al*., 1985).

High nutrient uptake in arrowroot reported with the application of N, P_2O_5 and K_2O @ 50, 25 and 75 kg ha^{-1} (Suja *et al*., 2006).

Anju *et al*. (2017) observed that the nutrient dose, 60:30:120 kg NPK ha^{-1} through fertilizers recorded the highest starch (72.41 %) on dry weight basis, protein content (7.04 %) and the highest uptake of N, P and K (57.09, 26.28 and 120.68 kg ha^{-1} respectively). The proportion in uptake of N, P and K remained similar to the ratio in which the nutrients were supplied (2:1:4). Suja *et al.* (2021) documented significant influence of organic management practices on P and K uptake in Chinese potato.

Studies on integrated nutrient management for coleus by Archana (2001) revealed that quality parameters of tuber such as starch content and protein content were not influenced by fertilizers.

John *et al*. (2005) opined that balanced application of 100 kg N, 50 P_2O_5 and 100 kg K_2O ha^{-1} along with FYM 12.5 t ha^{-1} improved the starch content of cassava tubers. Improved quality of sweet potato tubers was observed with application of N and P_2O_5 @ 50 kg ha^{-1} each (Laxminarayana and Burman, 2013). Application 50 kg of N through chemical fertilizers and 50 kg N from FYM along with 50 kg P and 150 kg K resulted in significantly higher starch content in elephant foot yam (Navya *et al*., 2017).

2.1.2.5 Effect of Nutrient Management on Soil Properties

George *et al*. (2000) observed that combined application of FYM and NPK fertilizer in cassava increased the availability of N, P and K in soil. Later Suja *et al*. (2006) documented substantial improvement in the nutrient status with the application of 50:25:75 kg NPK ha^{-1} in arrowroot. However, in her experiments Archana (2001) could not discern any significant variation in soil NPK status with the application of organic manures and fertilizers.

Suja and Sundaresan (2008) reported that the organic plots of elephant foot yam showed significantly higher available P status, slightly higher pH, organic C, available N and K status after three years of experimentation. On the contrary, bulk density, particle density and microbial activity remained similar in the four production systems *viz*., conventional, traditional, organic and biofertilizers (Suja *et al*., 2012). Onwudike (2010) recommended integrated application of cow dung @ 3 t ha^{-1} along with 100:100:100 kg N, P_2O_5 and K_2O ha^{-1} in sweet potato for improved soil fertility.

Nutrient management in coleus significantly influenced the soil pH and a lowered pH was exhibited in recommended dose of 60:60:100 kg NPK ha^{-1} and modified nutrient dose of 60:30:120 kg NPK ha^{-1} through chemical fertilizers compared to organically manured plots (Anju, 2014). The study also revealed higher organic carbon content (1.12 %), available N (235.20 kg ha^{-1}) and K (213.70 kg ha^{-1}) with nutrient dose of 60:30:120 kg NPK ha^{-1} was recorded compared to the recommended dose of 60:60:100 kg NPK ha^{-1}.

Kafle *et al.* (2019) cited that the influence of integrated nutrient management practices on bulk density of soil after the cultivation of potato was non-significant and the plots receiving 50 per cent recommended dose of NPK through inorganic fertilizers and remaining 50 per cent recommended dose of N through poultry manure registered the highest available N, P and K status in the soil. According to Suja *et al.* (2021), higher soil pH, organic carbon and available N and P, were observed with organic management of Chinese potato over conventional and integrated practices.

2.1.2.6 Effect of Nutrient Management on Economics

Nutrient application adds to the cost of cultivation on account of the input cost and labour involved in its application. But it is interpreted that the higher yields realised would compensate for the cost incurred rendering the practice economical. Suja (2005) reported that application of coir pith compost @ 5 t ha^{-1} along with 80, 60 and 80 kg ha^{-1} N, P_2O_5 and K_2O in white yam intercropped in coconut garden resulted in higher net income and BCR. Suja and Sundaresan (2008) reported an additional income of ₹ 58,345 ha^{-1} with organic farming compared to conventional practice in elephant foot yam. Higher net income (₹ 163900 ha^{-1}) and BCR (1.84) were registered in Chinese potato with the modified nutrient dose 60:30:120 kg NPK ha^{-1}) compared to the KAU recommended dose (60:60:100 kg NPK ha^{-1}) through fertilizers and organic manures (Anju, 2014). Application of 50 per cent of recommended dose of N through poultry manure and 50 per cent through inorganic fertilizers resulted in increased BCR in potato (Kafle *et al*., 2019). However, Suja *et al*. (2021) reported that the gross income and net income did not differ markedly with organic management practices in Chinese potato.

2.1.3 Consortium Biofertilizers

Biofertilizers are formulations of microbial inoculants which enhance production by improving the nutrient supplies and their crop availability (Wani and Lee, 1995). In the recent years, biofertilizers have received much acceptance and research interest due to ecological impacts associated with the use of chemical fertilizers (Odoh *et al*., 2020). Microbial formulations could be organism-specific or a consortium of organisms, the latter endowing multiple benefits especially in enhancing nutrient availability due to the different organisms involved.

The consortium biofertilizer, PGPR Mix 1, developed in the Department of Agricultural Microbiology, College of Agriculture, Vellayani contains N fixers (*Azospirillum lipoferum*, *Azotobacter chroococcum*), P solubilizer (*Bacillus megaterium*) and K solubilizer (*Bacillus sporothermodurans*) which play a significant role in making available all nutrients in soil available for plant uptake.

The ability of PGPR strains to colonize the rhizosphere is influenced by the changes in different physico-chemical properties of rhizospheric soil such as soil pH, water potential, partial pressure of O_2 and plant exudation, as compared to the bulk soil (Griffiths *et al*., 1999). McCully (2001) documented that in soil, PGPR can colonize the rhizosphere- the surface of the root or even the superficial intercellular spaces of plant roots.

Plant Growth Promoting Rhizobacteria bring nutrient elements from atmospheric or mineral reserves into the soil ecosystem in soluble form and the roots take up the nutrients (Prasad *et al*., 2015). Improved growth, yield and quality parameters with biofertilizers containing bacterial N fixer, phosphate and K solubilizers have been illustrated (Youssef and Eissa, 2014).

The direct mechanisms consist of, the supply of nutrients to the plant (either by nitrogen fixation or solubilization), increasing iron bioavailability (through siderophore production) as well as the production of phytohormones, like indole acetic acid (Ferreira *et al*., 2019).

2.1.3.1 Effect of Consortium Biofertilizers on Growth Attributes

In a field experiment at Madurai on sandy loam soil, Ravi (2004) recorded higher growth parameters like plant height, number of laterals, number of leaves and plant spread with the application of 50 : 60 kg N and P_2O_5 per ha along with biofertilizers in coleus. Yasmin *et al*. (2007) demonstrated increased growth attributes in sweet potato with inoculation of PGPR. Promising results of enhanced plant height and stem number (Ekin *et al*., 2009) and leaf area (Oswald *et al*., 2010) in potato have been reported.

Application of biofertilizer consortium, PGPR Mix 1, at 2 per cent along with the basal dose of organic manures in coleus recorded significantly higher number leaves and leaf area index at 30 DAP compared to that without PGPR Mix 1 (Jayapal, 2012). The study also revealed non significant effect on plant height, number of branches and number of leaves at 2 and 4 MAP due to the application of PGPR Mix 1. Effect of biofertilizers on plant growth in *C. vettiveroides* was studied by Desai and Thirumala (2014) and concluded that increased growth parameters like plant height, number of leaves in plants applied with FYM along with biofertilizers as compared to the sole application of organics or inorganics. Significantly taller plants were recorded in the combination 100 per cent recommended dose of fertilizers + FYM + biofertilizer (72.29 cm) in medicinal coleus (Sathiyaraj, 2017).

2.1.3.2 Effect of Consortium Biofertilizer on Physiological Parameters

Archana (2001) examined the influence of biofertilizers on physiological parameters of coleus variety Sree Dhara and the effects on DMP, LAI and RGR were found to be comparable. The study revealed significantly higher CGR (2.87) and NAR (2.91) during 120 DAP to harvest with the application of biofertilizer.

Oswald *et al*. (2007) recorded 20-30 per cent increase in yield of potato with the application of commercially available PGPR. Yasmin *et al*. (2007) examined the effect of PGPR inoculation on DMP of sweet potato and observed increased shoot and root dry weights with the inoculation compared to without inoculation.

Significantly higher dry matter per cent in elephant foot yam (23.89 %) was observed with biofertilizer application (Suja and Sundaresan, 2008). Application of FYM (282.80 g per plant) or inorganic fertilizer (312.73 g per plant) along with biofertilizer recorded higher biomass accumulation of *C. vettiveroides* as compared with sole application of FYM (210.49 g per plant) or inorganic fertilizer (261.56 g per plant) at 130 DAP (Mamata, 2009). Production systems involving biofertilizers resulted in significantly higher dry matter (21.67 %) which was comparable with organic and traditional systems of cultivation in elephant foot yam (Suja *et al*., 2012).

Jayapal *et al*. (2013) observed that PGPR Mix 1 treated plots produced significantly higher LAI of 4.03 at 1 MAP and dry matter of 6.73 t ha^{-1} at harvest compared to the non treated plant growth. The beneficial effects of biofertilizers in conjunction with organic and inorganic fertilizers compared to sole application in different species of Coleus have been reported (Ravikumar *et al*., 2013; Desai and Thirumala, 2014; Sathiyaraj, 2017). Growth attributes in cassava were significantly superior with inclusion of PGPR Mix 1 in the nutrient management strategy compared to that without PGPR.

2.1.3.3 Effect of Consortium Biofertilizers on Yield Attributes and Yield

Pot and field experiments conducted in potato with inoculation of PGPR (Javed and Arshad, 1999) revealed a significantly higher number of tubers and tuber yield. Yield attributes (number of tubers per plant, weight of tubers per plant, weight of marketable tubers per plant) were not influenced by the inoculation of biofertilizer in coleus except number of marketable tubers per plant wherein it was reduced significantly from 13.69 to 11.75 with the inoculation (Archana, 2001). In medicinal coleus, Ravi (2004) recorded higher yield attributes like length and diameter of tuberous roots, fresh and dry weight of roots per plant with the application of 50 : 60 kg N and P_2O_5 per ha along with biofertilizer in medicinal coleus. Increased storage root weight and total yield in sweet potato were recorded with the application of PGPR (Yasmin *et al*., 2007). Similar results with PGPR were documented in potato (Ekin *et al*., 2009; Helaly *et al*., 2009) and sweet potato (Pérez-Pazos and Sánchez-López, 2018).

Inoculation with the PGPR *Pseudomonas fluorescens,* improved potato yield (Behbood *et al*., 2012). Number of tubers (29.17), marketable tubers per plant (12.47), tuber weight (107.58 g), marketable tuber weight (92.72 g) and percentage weight of marketable tubers (86.14 %) per plant were significantly higher with the application of PGPR Mix 1 in coleus compared to without the application of biofertilizer (Jayapal, 2012). Ravikumar *et al*. (2013) documented superior values for the different yield attributes in medicinal coleus with the application of biofertilizer along with organic and inorganics. Root weight of *C. vettiveroides* was found to increase in the treatment combination, organic + biofertilizers compared to that without biofertilizers (Desai and Thirumala, 2014).

Inoculation of PGPR had significant effect on yield of potato (Hassani *et al*., 2015). PGPR significantly increased the weight of potato tubers with an average production of 277.1 g per plant (Purwantisari *et al*., 2019). PGPR inoculation significantly increased storage root number and yield in sweet potato (Yasmin *et al*., 2020) and cassava (Babu, 2020). Muruganandam *et al*. (2021) concluded that the combined use of inorganic fertilizers, organic fertilizers, and bio-fertilizers recorded maximum tuberous root yield in medicinal coleus.

2.1.3.4 Effect of Consortium Biofertilizers on Nutrient Uptake and Quality

Significant effects of PGPR on the nutrient concentration in shoots and roots of sweet potato were recorded by Yasmin *et al*. (2007). According to Suja and Sundaresan (2008), significantly higher starch and reducing sugars on fresh weight basis were recorded with biofertilizer application in elephant foot yam. Use of PGPR significantly increased crude protein, starch, non reducing sugar and N, P and K contents in potato (Helaly *et al*., 2009).

Dhanya (2011) examined the effect of consortium biofertilizer, PGPR Mix 1 on the nutrient uptake and quality in sweet potato and concluded that bioinoculation of PGPR Mix 1 significantly increased P uptake (8.6 kg ha^{-1}) and starch content (18.38 %) compared to no inoculation (7.42 kg ha^{-1} and 15.21 %), while N and K uptake did not differ markedly. Behbood *et al*. (2012) reported increased concentration of macronutrients in leaves and improved quality of potato tubers with the inoculation of PGPR. According to Jayapal (2012), N (70.71 kg ha^{-1}), P (24.42) and K (137.09 kg ha^{-1}) uptake in coleus were significantly higher with the application of PGPR Mix 1 compared to that without its application (54.69, 20.87 and 114.79 kg ha^{-1} respectively).

Inoculation of PGPR increased the nutrient uptake in potato (Hassani *et al*., 2015) and significant variations in the starch content in potato tubers with organic nutrient management was recorded by Ram *et al*. (2017), the highest being in the treatment involving biofertilizers. Babu *et al*. (2020) studied the effect of consortium biofertilizer PGPR Mix 1 on quality parameters in cassava and recorded superior values for PGPR Mix 1 included treatments, the maximum starch content being with PGPR Mix 1 liquid @ 5 per cent (27.81%). Quality in terms of N, P and K content in cassava tubers were also higher with the application of PGPR Mix 1. Yasmin *et al*. (2020) reported the significant influence of PGPR inoculation on starch and crude protein content in sweet potato. The enhancement in N, P, K, Ca and Mg content in tubers with the application of PGPR was also elucidated.

2.1.3.5 Effect of Consortium Biofertilizers on Soil Properties

Application of biofertilizer resulted in similar soil physical properties like bulk density, particle density and porosity compared to conventional, traditional and organic production systems in elephant foot yam (Suja *et al*., 2012).

The positive influence of biofertilizers on the physical, chemical and biological properties of soil has been elaborated in various crops by several workers. It is presumed that the biological activity of the microbial inoculants aids in mobililising the availability and recovery of nutrients thus improving soil quality in total (Yadav and Sarkar, 2019).

A build-up of available nutrients in soil was documented by Rani *et al.* (2008) with the addition of organic manure and biofertilizers in medicinal coleus (*C. forskohlii*).

Dhanya (2011) studied the influence of inoculation of PGPR Mix 1 on soil available NPK in sweet potato and reported significantly higher available K with PGPR Mix 1 (251.9 kg ha^{-1}) compared to without PGPR Mix 1 (206.9 kg ha^{-1}). Available N and P were not significantly influenced by the bioinoculants.

According to Jayapal (2012), application 2 per cent PGPR Mix 1 in coleus did not bring significant variations in organic C content and available N in the post harvest soil whereas high available P (61.10 kg ha^{-1}) and K (118.21 kg ha^{-1}) were higher with the application of PGPR compared to without PGPR (54.95 and 111.66 kg ha^{-1}).

Inoculation of PGPR significantly influenced the dehydrogenase activity in medicinal coleus (Priya and Kumutha, 2013).

Babu (2020) investigated the effect of application of biofertilizer consortium PGPR Mix 1 in cassava and revealed that, without the application of biofertilizer record the soil bacteria, fungi and actinomycete counts were significantly lower compared to all other treatments involving biofertilizer. Significantly the highest bacterial population was recorded in PGPR inoculated plots compared to un inoculated sweet potato grown soils (Yasmin *et al.*, 2020).

2.1.3.6 Effect of Consortium Biofertilizers on Economics

The inclusion of biofertilizers in the nutrient management practices in tuber crops has added to the cost of cultivation, but the income realized with the higher yield could compensate for the additional cost incurred (Babu, 2020).

The significantly highest B: C ratio (4.46) was computed in the plots with co-inoculation of P solubilizing bacteria and *Azotobacter* in potato (Choudhary *et al.*, 2010).

Application of biofertilizer resulted in significantly higher net income in coleus (Jayapal, 2012). Ravikumar *et al*. (2013) reported that application of organics and inorganics along with biofertilizers recorded higher net returns (₹ 22965 ha^{-1}) and BC ratio (1.48) in medicinal coleus compared to RD of NPK (40:60: 50 kg ha^{-1}) and FYM (15 t ha^{-1}). This was confirmed in the research works of Sathiyaraj (2017).

2.1.4 Growth Promoters

The significant roles of growth promoters in tuberization and yields have been elucidated in coleus (Rajmohan, 1978), sweet potato (Arya, 2019) and potato (Alexopoulos *et al*., 2006). It is stipulated that the role of the growth promoters varies with the type used, and among the commonly recommended promoters, cytokinins and humic acid are archived to be effective in canopy development (source) and tuberisation (sink).

Studies on the effect of growth promoters in tuber crops are mostly concentrated on potato and to a lesser extent in sweet potato and hence the available literature are included in the review.

2.1.4.1 Humic Acid

Sharif *et al*. (2002) opined that humic acid (HA), a naturally occurring polymeric organic compound produced during decomposition of organic materials, can be used for growth regulation in plants. The beneficial effects of humic acid is on account of the elements it contains, which improve soil fertility, reduce soil nutrient deficiency and increase water and nutrient availability by forming chelates of various nutrients (Bohme and Lua, 1997; Sanchez-Sanchez *et al*., 2002).

The plant growth promoting effect of humic substances (HS) is ascribed to the changes on root architecture and growth dynamics, which result in increased root size, branching and/or greater density of root hair with larger surface area

(Canellas and Olivares, 2014). According to Man-hong *et al*. (2020), humic acid could improve the plant resistance to mitigate the abiotic drought damages, which is regarded as a potential strategy to improve the crop production in arid and semi arid regions.

2.1.4.1.1 Effect of Humic Acid on Growth Attributes

Improved growth was observed in tapioca with combined application of N, P, K and humic acid spray (Mailappa, 2003). Positive influence of humic acid on potato growth has been reported by Matysiak and Adamczewski (2010). El-Deen *et al*. (2011) studied the effect of application methods of humic acid in sweet potato and found that the foliar application @ 0.5 per cent increased the main stem length and leaf area significantly. Similar results of increased leaf area with the foliar application of humic acid were also observed in potato by Juboori *et al*. (2012) and in sweet potato by Hameda *et al*. (2011) and Al-Esaily and El-Naka (2013).

Application of humic acid (2 g L^{-1}) recorded a significant increase in plant height, main stem diameter and total leaf number in potato compared to without its application (Al-Doghachi *et al*., 2016). Improvement in vegetative growth traits with the application of humic acid in potato has been reported by Alenazi *et al.* (2016), Shah *et al.* (2016) and Arafa and El-Howeity (2017). A concentration of 1000 ppm was adjudged superior (Harfoush *et al*., 2017). Similarly, significant improvement in number of branches, number of leaves and leaf area in potato with foliar application of HA were also reported by Saeid and Yousif (2018). Wadas and Dziugieł (2019) recorded higher leaf area with the application of humic substances compared to without its application.

2.1.4.1.2 Effect of Humic Acid on Physiological and Biochemical Parameters

The beneficial influence of humic acid includes enhanced membrane permeability, oxygen uptake, respiration, photosynthesis, phosphate uptake and root elongation (Russo and Berlyn, 1990). El-Deen *et al*. (2011) and Hameda *et* *al.* (2011) recorded higher total chlorophyll content, canopy dry weight and dry matter of tuberous roots in sweet potato. Al-Esaily and El-Naka (2013) observed increased photosynthetic pigments with increasing concentration of humic acid from 0 to 0.4 per cent in sweet potato. Significantly higher chlorophyll content (32.5 mg 100g^{-1} FW) was recorded with the application of 1000 ppm humic acid compared to without its application in potato (28.8 mg 100g^{-1} FW) (Harfoush *et al.*, 2017).

Sathiyaraj (2017) studied the effect of various plant growth regulators on the dry matter production of medicinal coleus and found higher DMP (10.01 t ha^{-1}) with the application of humic acid compared to water spray (8.51 t ha^{-1}).

2.1.4.1.3 Effect of Humic Acid on Yield Attributes and Yield

Application of humic acid at 6 g L^{-1} and 8 g L^{-1} significantly increased the tuber yield in potato (Abd-El-Kareem *et al.*, 2009) and the increase with foliar application was reported as 13 per cent (Verlinden *et al.*, 2009).

El-Deen *et al.* (2011) observed significantly higher average tuber root weight, marketable tuber yield and tuber yield in sweet potato with the application of humic acid compared to without its application. The results were corroborated by Hameda *et al.* (2011) in sweet potato and several authors in potato (Radwan *et al.*, 2011; Juboori *et al.*, 2012; Shah *et al.*, 2016). Studies conducted by Al-Doghachi *et al.* (2016) in potato revealed that application of humic acid (2g L^{-1}) produced a significantly higher number of tubers per plant, tuber yield per plant and marketable and total yield per unit area compared to no humic acid application. Alenazi *et al.* (2016) further illustrated that humic acid application could increase the production of all categories of tubers in potato. The increase in the number of large sized tubers was 47.1 to 56.0 per cent and, during both years recorded higher tuber fresh weight (135.44 and 137.9 g), tuber diameter (6.59 and 6.71 cm) and specific gravity (1.21 each). Similar results of increased yield attributes and yield in potato with foliar application of humic acid were also documented (Harfoush *et al.*, 2017; Saeid and Yousif, 2018).

According to Wadas and Dziugieł (2019), application of the bio stimulant HumiPlant in potato resulted in significantly higher marketable tuber yield (35.29 t ha^{-1}) compared to without its application (32.86 t ha^{-1}).

2.1.4.1.4 Effect of Humic Acid on Nutrient Uptake and Quality

Humic acid application has beneficial effects on plant nutrient uptake, N, P, K, Mg, Ca, Zn, Fe, and Cu (Fagbenro and Agboola, 1993). Increased nutrient uptake with humic acid application has been elucidated in potato (Verlinden *et al*., 2009; Radwan *et al*., 2011) and sweet potato (El-Deen *et al*., 2011; Hameda *et al*., 2011). The application of 50 per cent recommended doses of N, P and K and humic acid @ 0.03 per cent resulted in higher N (1.10 %) and P (0.06 %) content in potato (Shah *et al*., 2016). The K content in potato tuber was significantly increased by the application of humic substances (Dziugieł and Wadas, 2020).

Improved tuber quality with the application of humic acid was observed by Matysiak and Adamczewski (2010) in potato. Carbohydrate content was reported enhanced in sweet potato (Hameda *et al*., 2011). Foliar application of humic acid recorded higher NPK contents, crude protein and starch in potato tubers compared to the water spray (Arafa *et al*., 2012). Alenazi *et al*. (2016) examined the influence of humic acid on starch content of potato tubers and reported significantly higher starch content (18.85 and 18.96 %) during both the years of the experiment.

2.1.4.1.5 Effect of Humic Acid on Economics

Shah *et al*. (2016) reported that maximum net returns in potato in the treatment where humic acid was applied as foliar. The maximum BCR (5.35) was realized in treatment combination of ½ recommended dose of NPK in soil + foliar application of humic acid @ 0.03 per cent. Similarly, Sathiyaraj (2017) working on medicinal coleus reported a higher net return (₹ 114329 ha^{-1}) and BC ratio (4.1) with humic acid application compared to that with water spray (₹ 91,397 ha^{-1} and 3.7 respectively).

2.1.4.2 Benzyl Adenine

Benzyl adenine (BA) is a synthetic cytokinin. Cytokinins are N6-substituted aminopurines that act as plant growth regulators and influence the physiological and developmental processes of plants (Salisbury and Ross, 1992). Rather than initiating tuberisation, the role of cytokinins was seen in the regulation of tuber growth. The regulatory effect of cytokinins on source sink relationship during the tuberization of potato has been reported (Sarkar *et al*., 2006).

2.1.4.2.1 Effect of Benzyl Adenine on Growth Attributes

Foliar application of BA at 100 ppm in potato cultivar Asante resulted in significantly higher number of stems per plant (2.34) and leaflets per plant (218.4) (Njogu *et al*., 2015). Increased growth attributes in potato with the application of BA compared to without its application were documented by El-Hady *et al*. (2016), Nurjanah and Nuraini (2016), Lahijani *et al*. (2018) and Ahmed *et al*. (2021).

2.1.4.2.2 Effect of Benzyl Adenine on Physiological and Biochemical Parameters

Treating potato plants with BA increased the photosynthetic rate and maintained the photosynthetic activity longer than that of untreated control plants (Caldiz *et al*., 1998). According to Pospíšilová (2003), high concentrations of BA inhibited stomatal conductance and transpiration rate, while the lower concentrations enhanced them. Although cytokinin is not directly responsible for tuberization as reported by many workers, it was undoubtedly agreed that BA plays a key role in cell division and thus creating sink activity of the developing tuber which had a significant effect on the number, average weight and grade of microtubers in potato (Zakariya *et al*., 2008).

Aksenova *et al*. (2009) pointed that kinetin markedly increased the proportion of tubers as part of total plant biomass at the expense of a reduction in shoots. Aryakia and Hamidoghli (2010) reported that BA increases the size and weight of potato microtuber. The results were supported by the works of Roosta *et al*. (2015). Improved fresh and dry weights of potato were observed with foliar spray of BA (Lahijani *et al*., 2018).

Application of BA increased the chlorophyll a, chlorophyll b and dry weight of potato (El-Hady *et al*., 2016). Ahmed and Gebretensay (2019) recorded an increase in LAI by 52.9 per cent with the application of BA. In accordance with the above, Ahmed *et al*. (2021) also reported significantly higher foliage dry weight, chlorophyll a, chlorophyll b and total chlorophyll with the foliar spray of BA than without BA application.

2.1.4.2.3 Effect of Benzyl Adenine on Yield Attributes and Yield

An increase in total tuber yield by application of BA was documented in potato (Caldiz *et al*., 1998). Njogu *et al*. (2015) observed significantly higher number of tubers per plant and tuber yield in potato (8.60, 26.07 t ha^{-1} respectively) with the foliar application of BA 75 and 100 ppm in Asante cultivar. Cytokinins have a stimulating effect on microtuberisation. Larger and increased numbers of tubers were obtained in medium containing high levels of BA (Nisha and Purushothama, 2018). Application of BA increased the number of tubers and total tuber yield in potato cultivar Agria (Lahijani *et al*., 2018). Effect of exogenous application of BA on yield components and tuber yield in potato in Ethiopia was studied by Ahmed and Gebretensay (2019). Benzyl adenine significantly influenced the yield and yield components of potatoes such as tuber weight, marketable and total tuber yield per hectare. The lower concentration (0.1 mM) increased the average tuber weight by 62.80 per cent, marketable tuber yield by 70.55 per cent and total tuber yield by 65.81 per cent over the control water treatment.

However, Al-Deen and Their (2019) observed that increased levels of spraying BA significantly reduced the number of tubers per plant and tuber yield in potato cultivar Arizona and the spraying level was optimized as 5 mg L^{-1} for obtaining higher number of tubers per plant, tuber weight, tuber yield and protein content. Malek *et al*. (2021) studied the effect of various levels of BA on growth of potato cultivar Hermes, and reported BA at 30 mg L^{-1} to record the highest of tuber attributes and yield per plant and per hectare as compared to the control. Ahmed *et al*. (2021) also documented significantly higher average tuber weight and total tuber yield with the application of BA in potato. Based on their study, Nuraini *et al*. (2021) concluded that BA at 100 ppm was for higher tuber weights in potato.

2.1.4.2.4 Effect of Benzyl Adenine on Nutrient Uptake and Quality

Spraying of BA at 50 mg L^{-1} enhanced the NPK content of leaves, reducing sugar, non reducing sugar, starch content and protein content tubers of potato (El-Hady *et al*., 2016). On the contrary, Al-Deen and Their (2019) documented that the protein content was reduced significantly with BA application. Ahmed and Gebretensay (2020) observed that BA with low concentration (0.1 mM) recorded the highest (59.6 %) total starch content increment over the untreated control in Belete variety of potato. Tuber quality parameters like starch content (42.99 and 45.61 %) of potato increased with the application of BA in both the year of experiments (Malek *et al*., 2021). The authors also observed significantly higher N, P, K and B contents of tubers with spray application of BA 30 mg L^{-1} compared to control. Similar results of improved the NPK content of leaves and tubers with the application of BA were documented by Ahmed *et al*. (2021).

2.1.5 Carbon Dioxide Fertilization

In view of the ongoing changes in climate and the emerging food crisis, the innate advantages and climate resilience of tropical tuber crops to extreme and unpredictable variations need to be recognized (Nayar, 2014). Carbon dioxide is an essential component of photosynthesis and its supply in plants decides the sugar and carbohydrates available for growth. Photosynthetic assimilation of CO_2 is central to the metabolism of plants. As the concentration of CO_2

increases, plants show varied responses and the responses vary with the species (Rogers *et al.,* 1994).

It is well established that elevated CO_2 increases the growth and yield of most plant species (Kimball, 1983). The added growth and yield are primarily attributed to increased rates of photosynthesis and water use efficiency (Rogers and Dahlman, 1993; Amthor, 1995). Growth under eCO_2 conditions is characterised by a partial closure of leaf stomatal guard cells resulting in reduced transpiration and water loss which increases water use efficiency in plants with C_3 and C_4 photosynthetic pathways (Prior *et al*., 2011). However, research has shown that biomass response to atmospheric CO_2 enrichment is generally greater for plants with a C_3 photosynthetic pathway (33-40 % increase) compared to the 10-15 % increase in C_4 pathway (Prior *et al*., 2003; 2005). Plants with a C_3 photosynthetic pathway show both increased water use efficiency and increased photosynthesis, while the CO_2 concentrating mechanism used by C_4 plants limits their photosynthetic response to CO_2 enrichment (Amthor and Loomis, 1996).

2.1.5.1 Effect CO_2 Fertilization on Growth Attributes

Elevated concentrations of atmospheric CO_2 alter the phenology and rate of plant development. Bhattacharya *et al*. (1985) reported that high CO_2 concentrations enhanced the length of the main stem, total branch length, production of branches and leaf area in sweet potato.

Biswas *et al*. (1996) investigated the effects of CO_2 enrichment on sweet potato grown in open- top chambers in the field at four CO_2 levels ranging from 354 (ambient) to 665 ppm in two growing seasons. Results revealed that shoot growth was not affected significantly by eCO_2. Plants in open-top chambers at ambient CO_2 concentrations recorded reduced shoot growth in the first year and storage root yield in both years compared to that grown in the open field. However, in *Beta vulgaris*, Kumari *et al*. (2013) reported significantly higher shoot length, number of leaves and leaf area in plants grown under $eCO_{2.}$

Increased vine length and leaf area in Chinese yam (*Dioscorea opposita* Thunb.) under eCO_2 (ambient +200 ppm) were documented by Thinh *et al*. (2017).

2.1.5.2 Effect of CO_2 Fertilization on Physiological and Biochemical Parameters

Kimball (1983) elucidated a biomass increase of 10 to 143 per cent in several C_3 crops in response to doubled concentrations of ambient CO_2. On the contrary, Goudriaan and de Ruiter (1983) reported a negative response to CO_2 enrichment in terms of DMP of leaf, stem and tubers in white potato with damage to chloroplasts. Bhattacharya *et al*. (1985) observed an increase in specific leaf weight, leaf and stem weights, dry matter and greater partitioning of biomass to tubers than to roots at high CO_2 levels in sweet potato. Senescence of leaves and production of tubers accelerated as a result of long-term exposure of plants to eCO_2. It was concluded that CO_2 enrichment resulted in the modulation of sink capacity to enhance the production of tubers in sweet potato.

Cure (1985) and later Cure and Acock (1986) reported decreased stomatal conductance and aboveground biomass in potato when CO_2 concentration scaled to 550 ppm. Rogers *et al.* (1994) revealed photosynthetic reduction in some cases with long term exposure to elevated CO_2 concentration.

Increased earliness with higher CO_2 concentrations has been one reason lauded for enriching commercial greenhouses with CO_2 so as to shorten the time to market and reduce heating fuel costs (Enoch and Kimball, 1986). Hastening in leaf senescence and maturity of potato were noticed by Miglietta *et al*. (1998) with CO_2 enrichment. Elevated CO_2 caused earliness and senescence in potato and the decline in leaf area occurred two weeks earlier (Kimbal *et al*., 2002).

Increase in dry matter with elevated CO_2 has been documented in crops like turnip and radish (Wheeler *et al*., 1994; Bunce, 1997) and carrot (Usuda, 2006). In potato, the increases in dry matter of tubers were to the tune of 27 and 49 per cent during the first and second year of study with eCO_2 of 700 ppm

(Schapendonk *et al.*, 2000). Donnelly *et al.* (2001b) recorded increased above ground and below ground biomass with eCO_2 in potato. Fernandez *et al.* (2002) reported increased photosynthetic rate and shoot and dry matter of cassava with elevated CO_2. But according to Gleadow *et al.* (2009), eCO_2 reduced the total biomass in cassava.

Kimbal (2016) elucidated small increases in shoot biomass in potato, sugar beet, and cassava with elevated CO_2 whereas increases in tuber yield was 27 per cent in potato, 9 per cent in sugar beet and 109 per cent in cassava. Thinh *et al.* (2017) observed increased photosynthetic rate and dry matter with elevated CO_2 in Chinese yam. According to Cruz *et al.* (2018), increased dry matter of tuber roots (17.4 %) were observed in well-watered cassava plants. Runion *et al.* (2018) studied the growth and allocation of biomass of sweet potato cultivar CX-1 exposed to ambient and elevated (ambient + 200 ppm) CO_2 in open- top field chambers. They recorded increased biomass production under eCO_2 and 40.9 per cent increase in total storage root dry weight compared to plants grown under ambient CO_2. They also reported that allocation to belowground plant organs also increased under eCO_2 whereas dry weight partitioning remained unaffected. Increased tuber growth rate and total dry matter were observed under an eCO_2 of 700 ppm in potato (Chen and Setter, 2021).

2.1.5.3 Effect CO_2 Fertilization on Yield Attributes and Yield

Bhattacharya *et al.* (1985) opined that CO_2 enrichment resulted in the modulation of sink capacity to enhance the production of tubers in sweet potato. Carbon dioxide enrichment studies conducted in sweet potato for two seasons by Biswas *et al.* (1996) revealed that yield of storage roots of sweet potato increased nearly 46 and 75 per cent respectively at the highest CO_2 level (665 ppm). They also reported the increased number and size of the storage roots with the enrichment. Drake *et al.* (1997) reported that the photosynthesis benefits realized with eCO_2 are temperature dependent, due to Rubisco CO_2/O_2 substrate specificity and CO_2/O_2 solubilities, and are likely to diminish to zero at cooler temperatures. Miglietta *et al*. (1998) noted an increase in potato tuber growth of nearly 10 per cent for every 100 ppm CO_2 increase in free air CO_2 enrichment (FACE) and a 40 per cent enhancement in yield under 660 ppm CO_2. Increase in yield of potato with elevated CO_2 was also documented by Schapendonk *et al*. (2000) and Donnelly *et al*. (2001b).

Kimball *et al*. (2002) observed 28 per cent increase in potato tuber yield from free air CO_2 experiment. Elevated CO_2 concentration failed to produce significant effect on tuber initiation and increase in tuber number (Chen and Setter, 2012). They also observed enhanced tuber growth was observed under high CO_2 concentration (700 ppm) compared to 350 ppm treatment in potato.

Gleadow *et al*. (2009) reported decreased yield of cassava with eCO_2 (550 and 710 ppm).

Green house studies conducted by Zheng *et al*. (2018) using CO_2 concentration of 370 (the local atmospheric CO_2 concentration), 550 ± 50 and 750 ± 50 ppm revealed reported faster tuber formation in potato with CO_2 concentration of 550 ppm. They also added that tuber number per plant and tuber weight in potato with increased CO_2 concentration.

2.1.5.4 Effect CO_2 Fertilization on Nutrient Uptake and Quality

Bhattacharya *et al*. (1989) studied the changes in quality parameters like starch and protein in response to enriched CO_2 level in sweet potato and documented significantly higher starch content in 675 and 1000 ppm CO_2 grown plants than those grown in ambient CO_2 (350 ppm). But, protein and sucrose were found to decline. Studies on the effect of CO_2 levels on N concentration in the leaves of sweet potato revealed a decrease in N by 24 per cent at the highest CO_2 level (Biswas *et al*., 1996).

Reduced N content and increased starch content in potato with eCO_2 (550 and 680 ppm) were observed by Donnelly *et al*. (2001a). Kimball *et al*. (2002)

opined that increasing atmospheric CO_2 concentration would change the composition of plant material. The authors documented a greater reduction of N concentration in C_3 plants compared to C_4 plants. They also observed increased production of photosynthates and concentration of carbohydrates in the plant tissues with elevated atmospheric CO_2 concentrations and the concentration in leaves was most affected. Fangmeier *et al*. (2002) also reported significantly lower concentrations of N in aboveground organs and tubers of potato indicating the reduction in tuber quality at maturity grown under CO_2 enrichment.

Significantly higher N, P and K uptake (4.93, 1.25 and 9.14 g m^{-2}) by tubers were also noticed with elevated levels (680 ppm) compared to the ambient levels in open-top chamber study. According to Chen and Setter (2003), sucrose content of potato was unaffected by eCO_2.

Variable effects on quality of potato tubers with eCO_2 were reported by Hogy and Fangmeier (2009) wherein negative relation was observed for protein content in tuber with eCO_2. Meta-analysis by Taub *et al*. (2008) revealed that the mean reduction in protein in potato was 13.9 per cent with elevated CO_2. Elevated CO_2 reduced total leaf N in cassava (Gleadow *et al*., 2009). Kumari and Agrawal (2014) explored the influence of season-long exposure of CO_2 and ozone (O_3) on the quality of potato and noticed modification in the quality of the tubers.. Starch content of tubers increased by 130.6 per cent under elevated CO_2 (570 ppm) and ambient ozone (50 ppb) compared to ambient CO_2 (382 ppm) and ambient ozone (50 ppb). The protein content of tubers decreased significantly compared to ambient CO_2.

The reviewed literature brings to light the significance of resource management practices including land configuration, planting geometry, nutrient management and growth regulators in regulating the source-sink activities in tuber crops. The photosensitivity, low yield, and small size of the tubers are considered negative characteristics dampening the prospects of Chinese potato cultivation despite the high biological efficiency and nutritious quality of the tubers. The paucity of documented evidence on management strategies and options for source-sink modulation for higher marketable yields necessitates research to advocate recommendations for adoption. Carbon dioxide enrichment which is known to enhance photosynthesis in plants may have an influence on tuber yields as the source strength is enhanced. The present investigation is thus envisaged to formulate suitable resource management strategies to tackle the issue of low marketable yields in Chinese potato.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The experiment entitled “Resource management for source–sink modulation in Chinese potato [*Plectranthus rotundifolius* (Poir.) Spreng.]” was carried out at the Instructional Farm, College of Agriculture, Vellayani during 2019 - 2021. The investigation comprised two separate experiments (i) influence of method of planting, nutrient management and growth promoters on the source - sink relationship, tuber yield and quality in Chinese potato, and (ii) influence of carbon dioxide fertilization on the growth, yield and tuber quality of Chinese potato. The materials used and the methods adopted for the study are detailed in this chapter.

3.1 GENERAL DETAILS

3.1.1 Location

The experiments were conducted in the Instructional Farm, College of Agriculture, Vellayani, located at 8°25’43”N latitude, 76°59’98” E longitude and 29 m above mean sea level (MSL).

3.1.2 Climate and Season

The experiment I was laid out during the period, October to February of 2019 – ‘20 and 2020 – ‘21 and experiment II, during November to July of 2019-‘20 and October to March of 2020-‘21. The site experienced a humid tropical climate. The data on mean maximum and minimum temperature, mean relative humidity and rainfall during the experimental period were collected from the Class B Agrometeorological observatory, attached to the Department of Agricultural Meteorology, College of Agriculture, Vellayani and are presented in Appendix I to IV as standard week averages. The graphical representations of the data are given as Fig. 1a to 4c. In the first year, the total rain fall received during the cropping period was 1257.3 mm and it was 383.8 mm during the second year of experimentation.

3.1.3 Soil Characteristics

The mechanical composition of the soil is given in Table 1.

Table 1. Mechanical composition of the soil

Particulars	Content (%)	Method
Coarse sand	16.92	International pipette method (Piper, 1966)
Fine sand	30.52	
Silt	23.85	
Clay	27.81	

Soil of experimental site belonged to the sandy clay loam textural class.

The chemical and biological characteristics of the soil are furnished in Table 2.

3.1.4 Cropping History of the Experimental Sites

The experiment area was previously under banana cultivation for four years.

3.2 MATERIALS

3.2.1 Crop and Variety

The variety of coleus used for the study was Suphala, a photo insensitive variety released from College of Agriculture, Vellanikkara, Kerala Agricultural University. Suphala is a tissue culture mutant with thick dark green leaves, a duration of 120 -140 days and an average yield of 15.93 t ha^{-1}. Seed tubers for the experiments were made available from the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani.

3.2.2 Manures and Fertilizers

Farmyard manure (FYM) was procured from Department of Animal Husbandry, College of Agriculture, Vellayani and it contained 0.56, 0.32 and 0.38

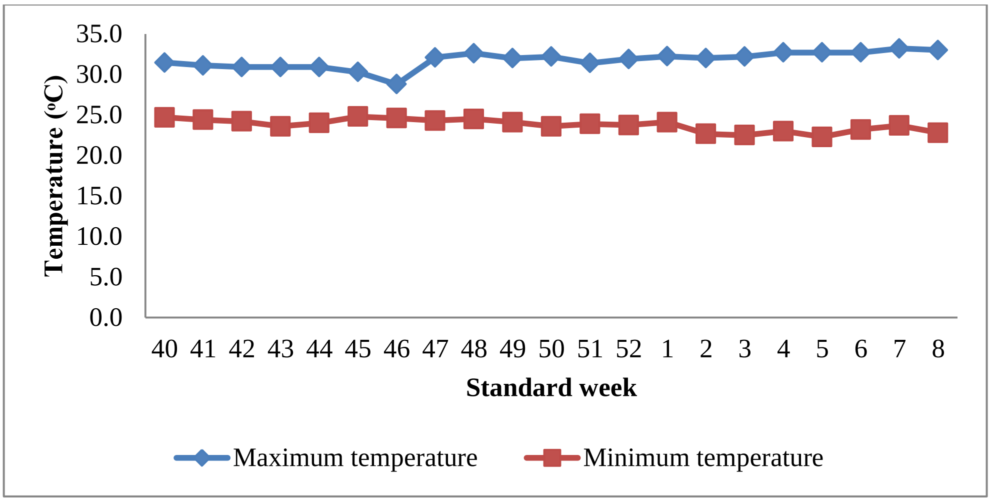


Fig. 1a. Maximum and minimum temperature during experiment I (2019-‘20), °C

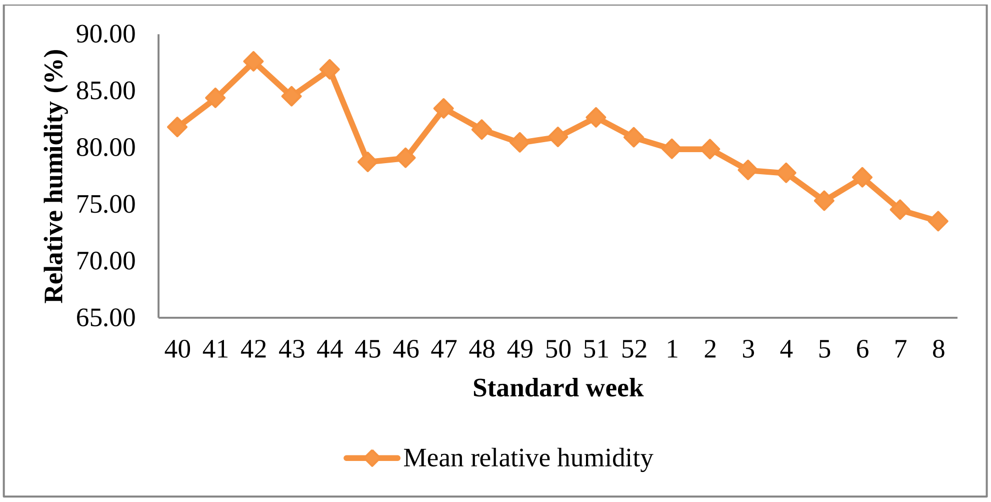


Fig. 1b. Mean relative humidity during experiment I (2019-‘20), per cent

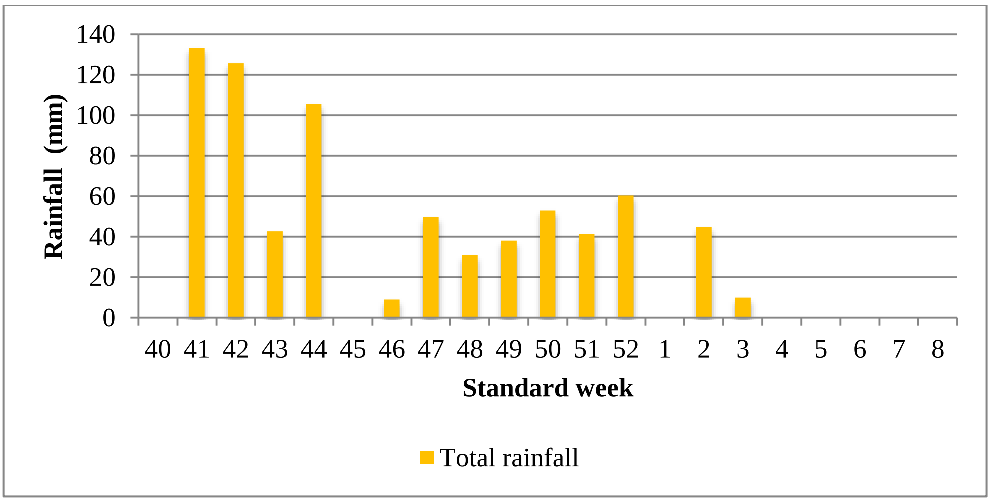


Fig 1c. Rainfall during experiment I (2019-‘20), mm

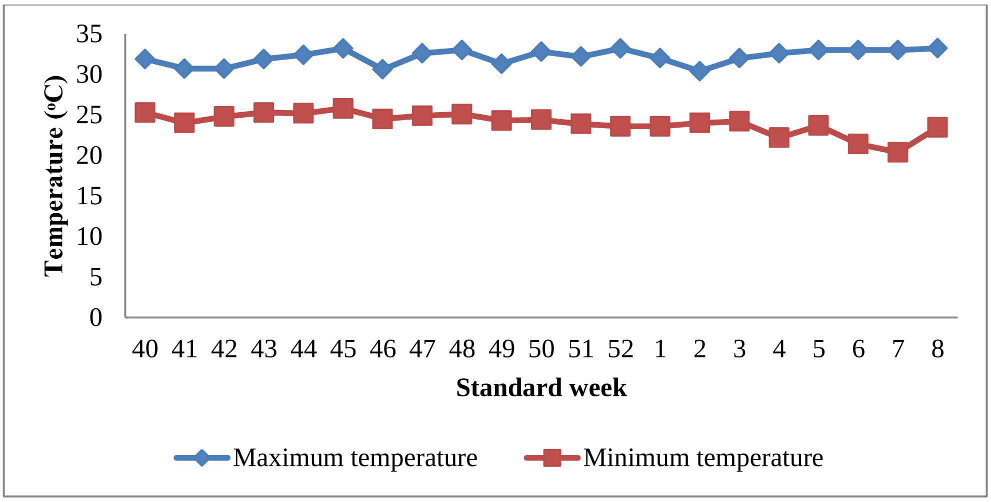


Fig 2a. Maximum and minimum temperature during experiment I (2020-‘21), °C

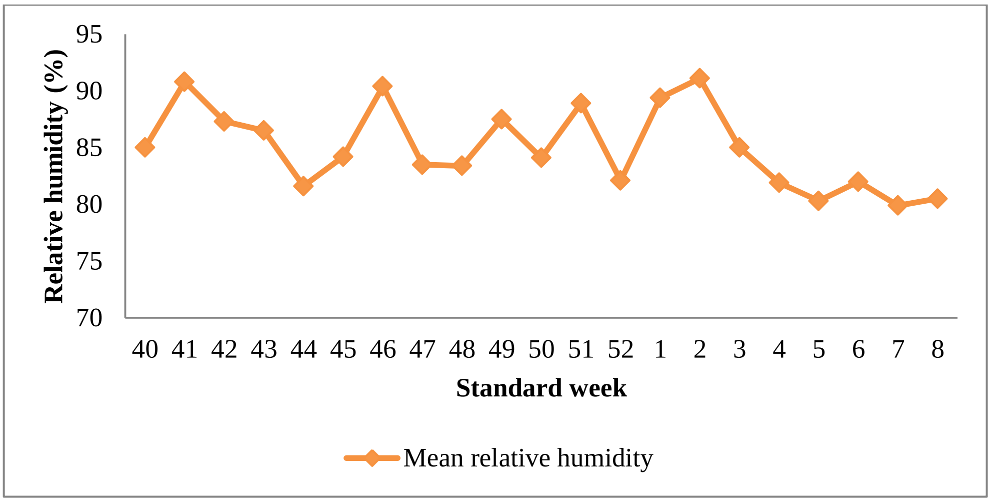


Fig. 2b. Mean relative humidity during experiment I (2020-‘21), per cent

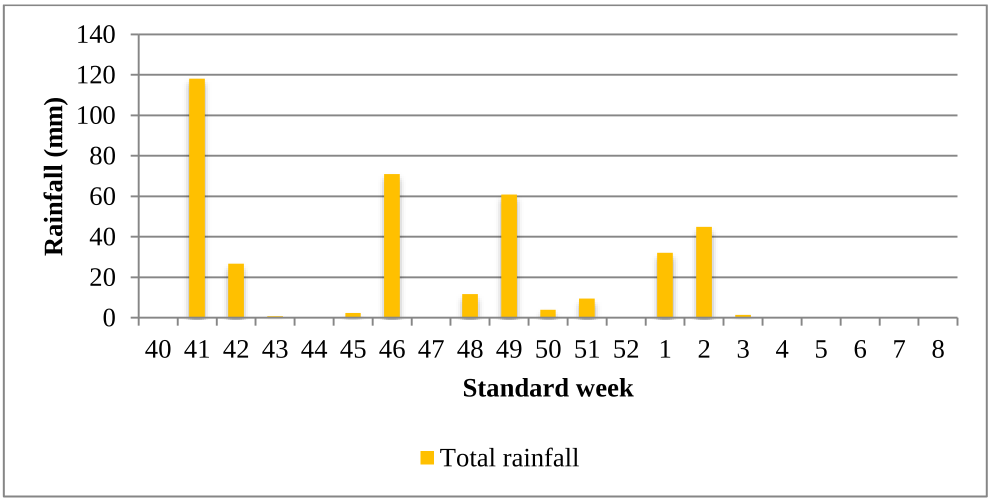


Fig. 2c. Rainfall during experiment I (2020-‘21), mm

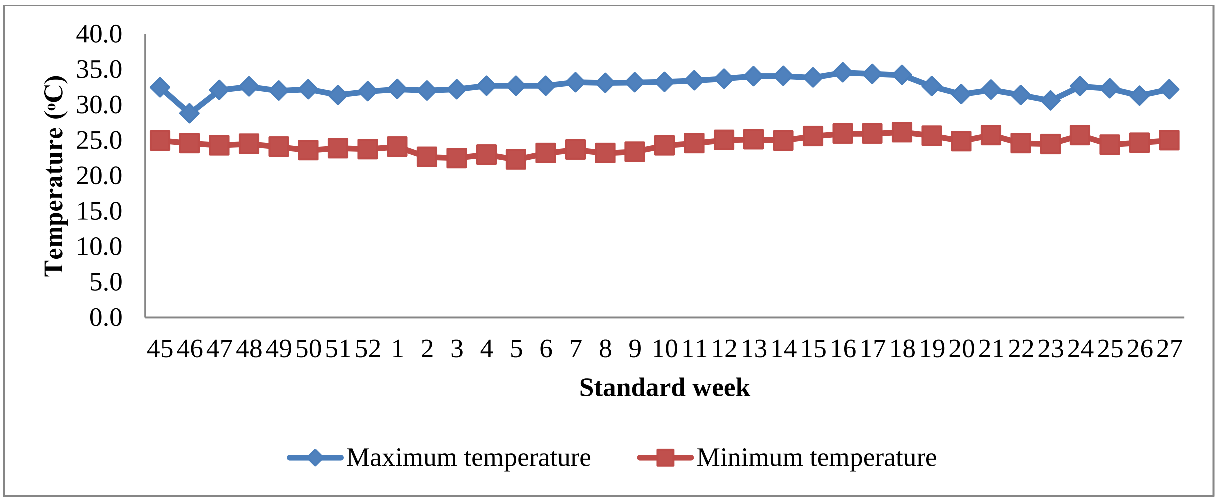


Fig. 3a. Maximum and minimum temperature during experiment II (2019-‘20), °C

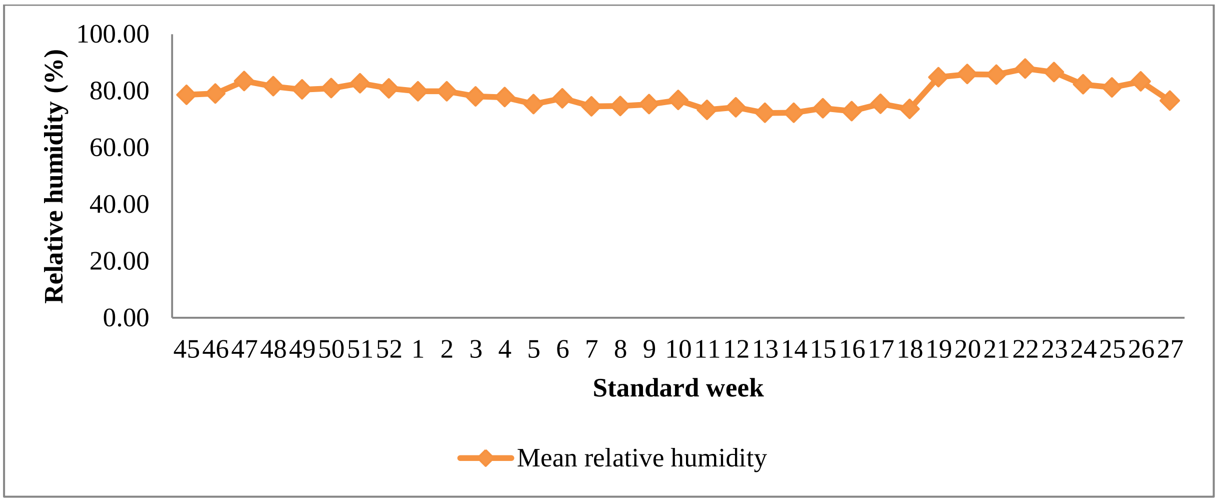


Fig. 3b. Mean relative humidity during experiment II (2019-‘20), per cent

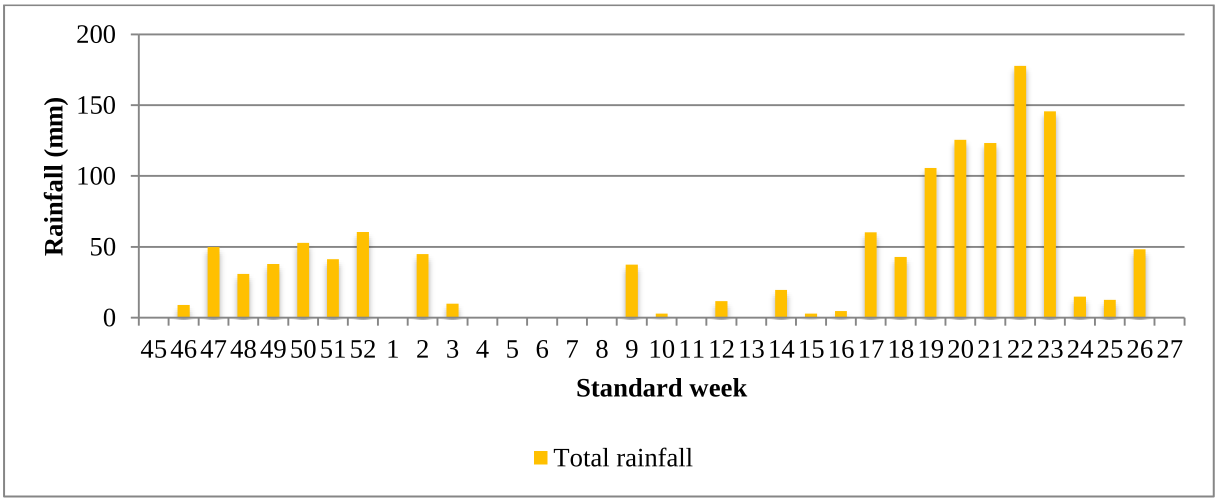


Fig. 3c. Rainfall during experiment II (2019-‘20), mm

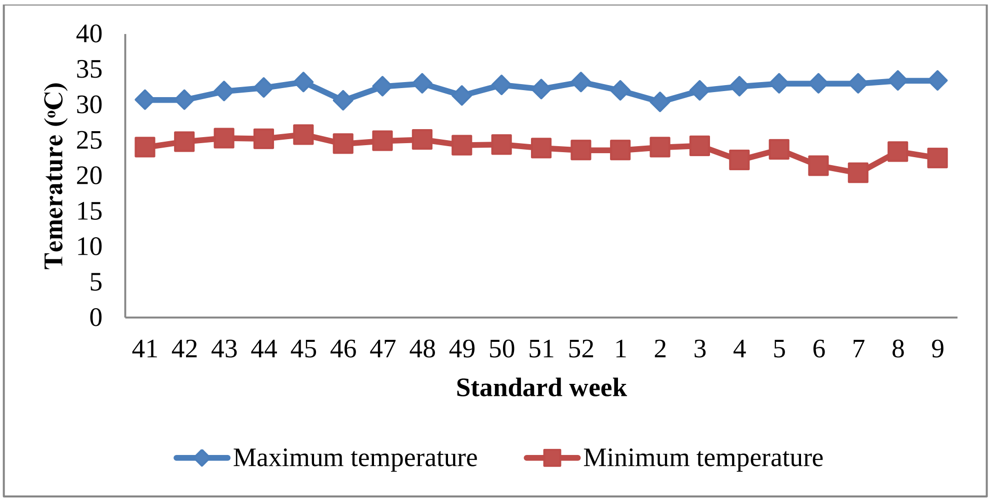


Fig. 4a. Maximum and minimum temperature during experiment II (2020-‘21), °C

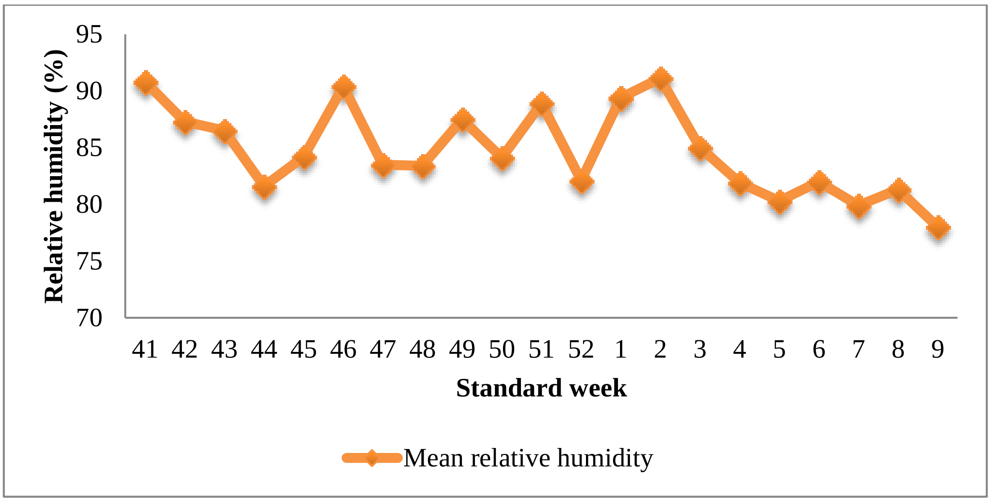


Fig. 4b. Mean relative humidity during experiment II (2020-‘21), per cent

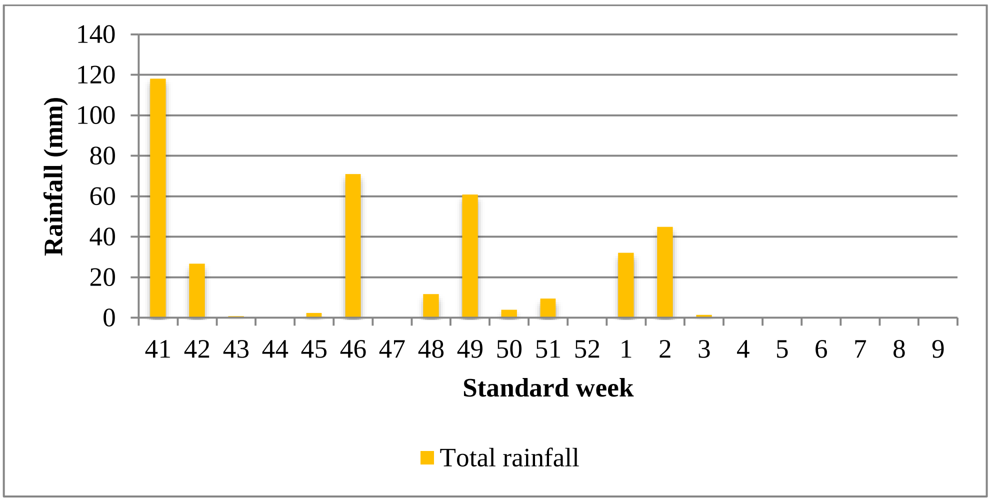


Fig. 4c. Rainfall during experiment II (2020-‘21), mm

per cent N, P and K respectively. Urea (46 % N), rajphos (20 % P_2O_5) and muriate of potash (60 % K_2O) were used as the chemical sources of nutrients for the experiments.

3.2.3 PGPR Mix 1

Talc based formulation of PGPR Mix 1 developed in the Department of Agricultural Microbiology, College of Agriculture, Vellayani was the biofertilizer included in the treatments. The consortium biofertilizer contained N fixers (*Azospirillum lipoferum*, *Azotobacter chroococcum*), P solubilizer (*Bacillus megaterium*) and K solubilizer (*Bacillus sporothermodurans*).

3.2.4. Growth Promoters

3.2.4.1 Humic Acid

Humic acid used was ‘All purpose organic humic acid’, purchased from Shiviproducts, Chhattisgarh. The pH and EC of humic acid were 11.94 and 1.7 dS m^{-1} respectively.

3.2.4.1. Benzyl Adenine

Benzyl adenine (BA) marketed as 6- Benzyladenine, 99 % Alfa Aesar™ was used for the experiment. The molecular formula of BA is $C_{12}H_{11}N_5$ and molecular weight, 225.255 g mol^{-1}.

3.2.5 Substrates for CO_2 Evolution

3.2.5.1 Cow Dung

Partially dried cow dung was collected from the Department of Animal Husbandry, College of Agriculture, Vellayani.

3.2.5.2 Coir Pith

Coir pith was purchased locally from Kalliyoor, Vellayani.

3.2.5.3 Pleurotus

Pleurotus eous spawn produced under the All India Co-ordinated Research Project (AICRP) on Mushroom, Department of Plant Pathology, was used in the CO_2 fertilization study.

3.3 METHODS

3.3.1 Experiment I: Influence of Method of Planting, Nutrient Management and Growth Promoters on Source - Sink Relationship, Tuber Yield and Quality in Chinese Potato

3.3.1.1 Experimental Design and Layout

Design	: Split plot design
Treatments	: 5 x 6
Replications	: 4
Period	: October 2019 - February 2020 October 2020 - February 2021

Plot size

Main plot : 14.4 m x 1.5 m

Sub plot : 2.4 m x 1.5 m

3.3.1.2 Details of Treatment and Layout

The treatments included five main plot and six sub plot treatments

Main plot - Methods of planting (M) : 5

m_1: Bed method (30 cm x 15 cm)

m_2: Bed method (30 cm x 30 cm)

m_3: Ridge method (30 cm x 15 cm)

m_4: Ridge method (30 cm x 30 cm)

m_5: Mound method (30 cm x 30 cm)

Table 2. Chemical and biological characteristics of the soil of the experimental site

Particulars	Content		Method
	2019-20	2020-21	
Chemical properties			
Soil reaction (pH)	6.05 (Slightly acid)	6.07 (Slightly acid)	1: 2.5 soil solution ratio using pH meter with glass electrode (Jackson, 1973)
Electrical conductivity (dS m^{-1})	0.19 (Normal)	0.23 (Normal)	1: 2.5 soil solution ratio using digital conductivity meter (Jackson,1973)
Organic C (%)	1.05 (High)	1.09 (High)	Rapid titration method (Walkley and Black, 1934)
Available N (kg ha^{-1})	301.06 (Medium)	307.33 (Medium)	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg ha^{-1})	27.24 (High)	32.00 (High)	Dickman and Bray's molybdenum blue spectrophotometer (Jackson, 1973)
Available K (kg ha^{-1})	327.04 (High)	341.17 (High)	Neutral normal ammonium acetate extraction and flame photometry (Jackson, 1973)
Biological properties			
Bacteria (cfu g^{-1} soil)	8×10^6	8.5×10^6	Serial dilution and plate count method (Johnson and Curl, 1972)
Fungi (cfu g^{-1} soil)	3×10^4	4×10^4	
Actinomycetes (cfu g^{-1} soil)	2×10^5	2.5×10^5	
Dehydrogenase activity (µg of TPF g^{-1} soil $24h^{-1}$)	15.40	16.57	TTC (Triphenyl Tetrazolium Chloride) reduction technique (Thalmann, 1968)

Sub plot - Combination of nutrient management and growth promoters

(N x G) : 2 x 3

a) Nutrient management (N) - 2

n_1: 60:30:120 kg NPK ha^{-1} + PGPR Mix 1

n_2: 60:30:120 kg NPK ha^{-1}

b) Growth promoters (G) - 3

g_1: Humic acid @ 5 g L^{-1}

g_2: Benzyl adenine @ 50 mg L^{-1}

g_3: Water spray

Treatment combinations: 30

$m_1n_1g_1$	$m_1n_1g_2$	$m_1n_1g_3$	$m_1n_2g_1$	$m_1n_2g_2$	$m_1n_2g_3$
$m_2n_1g_1$	$m_2n_1g_2$	$m_2n_1g_3$	$m_2n_2g_1$	$m_2n_2g_2$	$m_2n_2g_3$
$m_3n_1g_1$	$m_3n_1g_2$	$m_3n_1g_3$	$m_3n_2g_1$	$m_3n_2g_2$	$m_3n_2g_3$
$m_4n_1g_1$	$m_4n_1g_2$	$m_4n_1g_3$	$m_4n_2g_1$	$m_4n_2g_2$	$m_4n_2g_3$
$m_5n_1g_1$	$m_5n_1g_2$	$m_5n_1g_3$	$m_5n_2g_1$	$m_5n_2g_2$	$m_5n_2g_3$

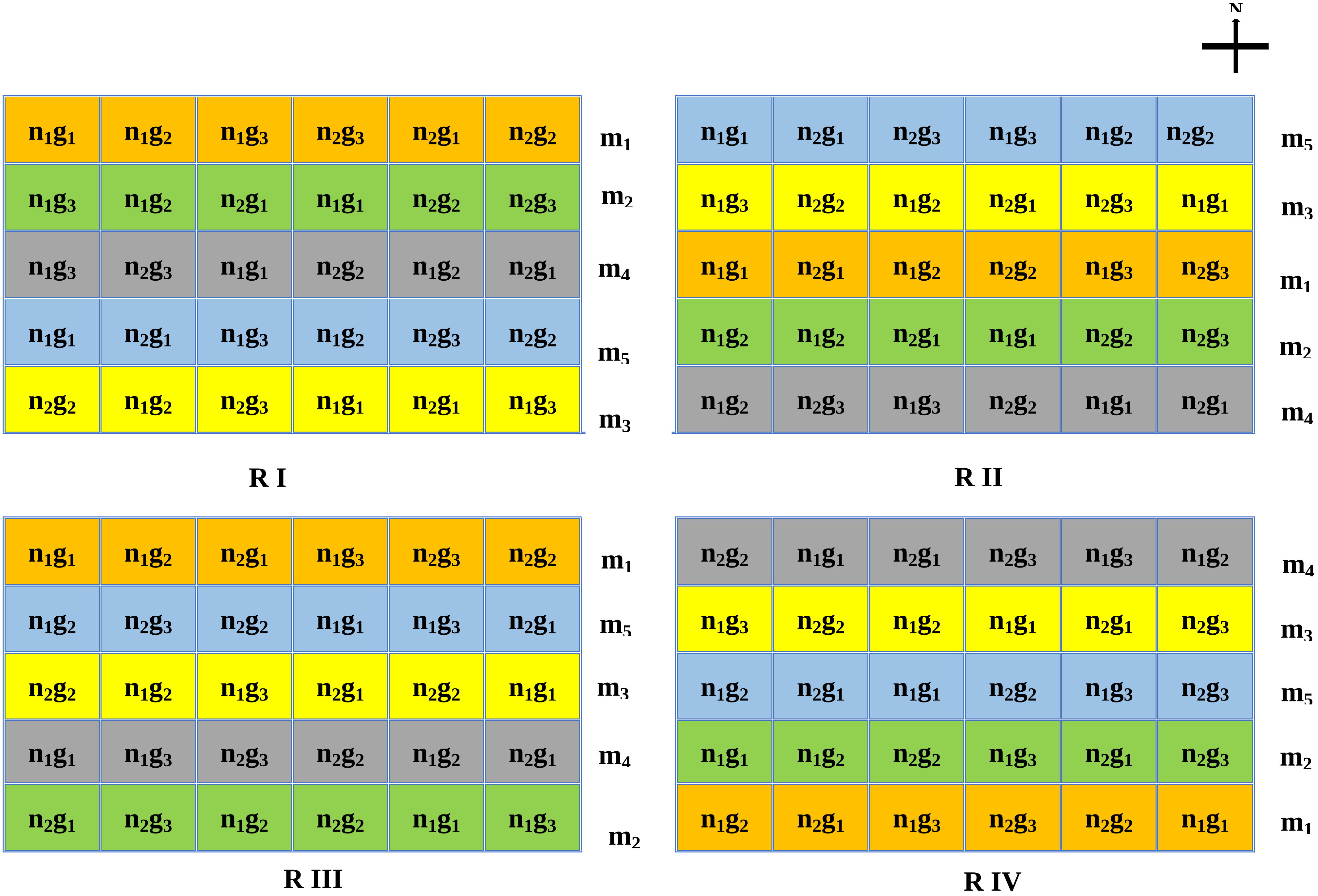
The layout of the experiment I is given in Fig 5.

3.3.1.3 Nursery

Seed tubers of Chinese potato were planted at a spacing of 15 cm on the ridges taken 30 cm apart in an area of 5.4 m^2 to raise cuttings for multiplication. A secondary nursery (9 m x 3.6 m) was prepared adjacent to the main field. The area was cleared, levelled and three beds of 9 m x 1.2 m were taken. Farmyard manure was incorporated @ 1 kg m^{-2} and cuttings of 10-15 cm length were planted at 30 cm x 15 cm spacing during second fortnight of August 2019 and 2020. The crop was irrigated and after 45 days of growth, cuttings were taken for planting in the main field.

3.3.1.4 Field Preparation

The field was ploughed to a depth of 25 cm with cultivator and later pulverized using rotavator. Lime was applied @ 100 kg ha^{-1} based on soil test data. The area was levelled after 10 days and divided into five main plots, each of size 14.4 m x 1.5 m. Each main plot was further divided into sub plots of size 2.4 m x 1.5 m each.



n_1g_1	n_1g_2	n_1g_3	n_2g_3	n_2g_1	n_2g_2	m_1
n_1g_3	n_1g_2	n_2g_1	n_1g_1	n_2g_2	n_2g_3	m_2
n_1g_3	n_2g_3	n_1g_1	n_2g_2	n_1g_2	n_2g_1	m_4
n_1g_1	n_2g_1	n_1g_3	n_1g_2	n_2g_3	n_2g_2	m_5
n_2g_2	n_1g_2	n_2g_3	n_1g_1	n_2g_1	n_1g_3	m_3

R I

n_1g_1	n_2g_1	n_2g_3	n_1g_3	n_1g_2	n_2g_2	m_5
n_1g_3	n_2g_2	n_1g_2	n_2g_1	n_2g_3	n_1g_1	m_3
n_1g_1	n_2g_1	n_1g_2	n_2g_2	n_1g_3	n_2g_3	m_1
n_1g_2	n_1g_2	n_2g_1	n_1g_1	n_2g_2	n_2g_3	m_2
n_1g_2	n_2g_3	n_1g_3	n_2g_2	n_1g_1	n_2g_1	m_4

R II

n_1g_1	n_1g_2	n_2g_1	n_1g_3	n_2g_3	n_2g_2	m_1
n_1g_2	n_2g_3	n_2g_2	n_1g_1	n_1g_3	n_2g_1	m_5
n_2g_2	n_1g_2	n_1g_3	n_2g_1	n_2g_2	n_1g_1	m_3
n_1g_1	n_1g_3	n_2g_3	n_2g_2	n_1g_2	n_2g_1	m_4
n_2g_1	n_2g_3	n_1g_2	n_2g_2	n_1g_1	n_1g_3	m_2

R III

n_2g_2	n_1g_1	n_2g_1	n_2g_3	n_1g_3	n_1g_2	m_4
n_1g_3	n_2g_2	n_1g_2	n_1g_1	n_2g_1	n_2g_3	m_3
n_1g_2	n_2g_1	n_1g_1	n_2g_2	n_1g_3	n_2g_3	m_5
n_1g_1	n_1g_2	n_2g_2	n_1g_3	n_2g_1	n_2g_3	m_2
n_1g_2	n_2g_1	n_1g_3	n_2g_3	n_2g_2	n_1g_1	m_1

R IV

Fig 5. Layout of experiment I during 2019-20 and 2020-21

Beds, ridges and mounds were prepared in the respective plots as per the treatments fixed. Raised beds of size 2.4 m x 1.5 m x 0.15 m were taken in m_1 and m_2. Ridges of size 30 cm width, 1.5 m length and 0.15 m height were taken, in north-south direction in m_3 and m_4. In m_5, mounds of 15 cm height were taken, 30 cm apart.

3.3.1.5 Planting

Terminal cuttings of 10-15 cm length taken from the disease free healthy plants in the nursery were planted during the first week of October in 2019 and 2020 for experiment I (first and second year respectively).

3.3.1.6 Application of Manures and Fertilizers

Farmyard manure was incorporated in soil @ 10 t ha^{-1} prior to the planting of the cuttings. The nutrient dose of 60:30:120 kg NPK ha^{-1} was adopted in which the entire dose of P_2O_5 was given as basal, and N and K_2O in two equal splits, basal and 45 DAP.

The biofertilizer PGPR Mix 1 was mixed with dried FYM @ 2 per cent (2 g in 100 g) and 5 g of the mixture was applied per plant thrice, basal, 30 and 60 DAP in the treatments involving PGPR.

3.3.1.7 Irrigation, Weeding and Earthing up

Irrigation was given as and when rains failed. Weeding and earthing up were done at 45 DAP along with top dressing. A portion of the vine was covered with soil to promote tuber formation.

3.3.1.8 Spraying of Humic Acid, Benzyl Adenine and Water

Humic acid @ 5 g L^{-1} (5 g humic acid in one litre of water), BA @ 50 mg L^{-1} (50 mg BA in one litre of water) and irrigation water were applied foliar, at the rate of 500 L ha^{-1} at 45 and 75 DAP in g_1, g_2 and g_3 respectively.

3.3.1.9 Plant Protection

Leaf webber (*Pycnarmon cribata*) infestation noticed at 35 DAP and was managed with chlorantraniliprole 18.5 EC (CORAGEN®) applied @ 3 mL 10 L^{-1}.

3.3.1.10 Harvesting

The crop was harvested when the top portion started drying, 140 and 143 DAP in first and second year respectively. Plants in the net plot area were harvested by digging out the tubers. The tubers were separated from shoots manually. The border row and observation plants were harvested separately in each plot.

3.3.2 Experiment II: Influence of CO_2 Fertilization on Growth, Yield and Tuber Quality in Chinese Potato

3.3.2.1 Design and Layout

Design	: Completely Randomised Design
Treatments	: 6
Replications	: 3
Variety	: Suphala
Period	: November 2019 - July 2020 October 2020 - March 2021

The layout of the experiment is depicted in Fig 6.

3.3.2.2 Treatment Details

s_0: No substrate
s_1: Cow dung
s_2: Coir pith
s_3: Cow dung + Coir pith (2:1)
s_4: s_2 + *Pleurotus* 1g kg^{-1} + N + P (2% w/w)
s_5: s_3 + *Pleurotus* 1g kg^{-1} + N + P (2% w/w)

Trench system adopted by Minu (2015) was used for the CO_2 fertilization study with minor modifications in the size and structure. Six trenches (2m x 1m x 1m) were prepared adjacent to the field of experiment I with Tata Hitachi and the trenches were lined with bricks to prevent sliding of the sides. Steps were also provided for entering the trench. A dome shaped covering as per the trench dimensions was fabricated with a metal frame and 200 µ uv stabilised polyethylene sheet to trap the CO_2 evolved in the trench. The trenches were kept covered from 4.00 pm to 10.30 am, and left open during the rest of the day for the entire crop growth period. *Pleurotus* was applied @ 1 g kg^{-1} of the substrate in s_4 and s_5, prior to application in the trench.

Plates 1a. Nursery of Chinese potato

Plates 1b. Main field preparation and planting

Plate 1c. Field view of the experimental plots

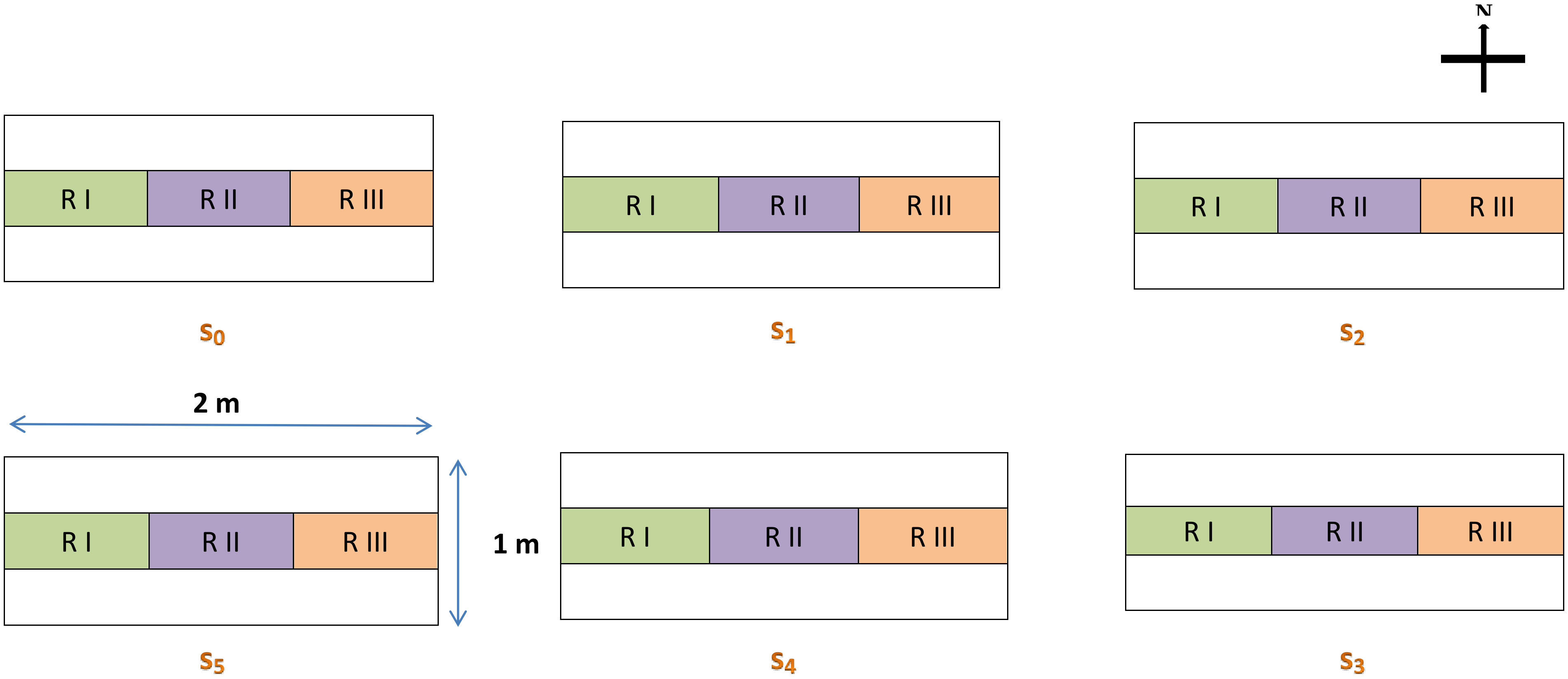


Fig. 6. Layout of experiment II during 2019-‘20 and 2020-‘21

A planting area of 2 m x 30 cm was marked in the middle of each trench and demarcated from the substrate spread at the base with polyvinyl chloride (PVC) sheet of height 60 cm and length 2 m. The sheets were fixed in soil at a depth of 30 cm to avoid direct contact of plants with the organic substrates spread in the trench. Cuttings of Chinese potato were planted in this marked area, directly in soil (first year) and in 150 gauge uv stabilized grow bags (24 cm x 24 cm x 40 cm) in the second year.

The experimental area was given a shade net fencing (1 m height) to prevent the entry of stray dogs and damage to the roofing of the trenches.

3.3.2.3 Preparation and Spreading of Organic Substrates

Weighed quantities of organic substrates prepared as detailed in Table 3 were spread on either the sides of PVC sheet to a uniform thickness of 5 cm.

Table 3. Quantity of substrates used in various treatments

Treatment	Quantity of substrate kg	*Pleurotus* G	N (Urea) kg	P (Rajphos) kg
s_0: No substrate	0	0	0	0
s_1: Cow dung	50	0	0	0
s_2: Coir pith	30	0	0	0
s_3: Cow dung + Coir pith (2:1)	40	0	0	0
s_4: s_2 + *Pleurotus* 1g kg^{-1} + N + P (2% w/w)	30	30	0.6 (1..30)	0.6 (3.00)
s_5: s_3 + *Pleurotus* 1g kg^{-1} + N + P (2% w/w)	40	40	0.8 (1.74)	0.8 (4.00)

3.3.2.4 Nursery

Cuttings for planting were raised in the nursery as described under section 3.3.1.3.

3.3.2.5 Growth Media

In the first year (2019-20), the soil of the planting area (2 m x 0.3 m) in the centre of the trench was mixed with top soil from the open area and the organic carbon status was analysed before planting. The initial organic carbon content estimated in soil by the rapid titration method (Walkley and Black, 1934) was 0.62 per cent.

For planting in grow bags in the second year, a potting mixture containing soil, sand and FYM in the ratio 1:1:1 was prepared and filled in the grow bags (14 kg each). The organic carbon content of the medium was 0.65 per cent.

3.3.2.6 Planting

Terminal cuttings of 10-15 cm length collected from nursery were used for planting. During 2019-20, cuttings were planted in the middle of marked area in a single row at a spacing of 15 cm in November 2019. A total of 12 plants were maintained in each trench (4 plants per replication).

In the second year (2020-21), single cuttings were planted in each grow bag and arranged in the planting area during the second week of October 2020. Six grow bags were placed in each trench (2 plants per replication).

3.3.2.7 Application of Manures and Fertilizers

A nutrient dose of 0.58: 0.67: 0.90 g NPK per plant was applied with chemical fertilizers (urea, rajphos and muriate of potash) as sources of N, P and K based on the recommended dose of nutrients, 60:60:120 kg ha^{-1} (KAU, 2016). The entire dose of P_2O_5 was given as basal, N and K_2O in two equal splits, basal and 45 DAP.

3.3.2.8 Irrigation, Weeding and Earthing up

Irrigation was done whenever rains failed and weeding, to maintain the planted area/ grow bags weed free. Earthing up was done at 45 DAP along with the top dressing of fertilizers.

Plates 2. Trench system of CO_2 fertilization

3.4 OBSERVATIONS

3.4.1 Experiment I

Three plants were selected randomly from the net plot area and labelled as observation plants.

3.4.1.1 Growth Attributes

3.4.1.1.1 Plant Height

Plant height was measured at 30 days interval from the observation plants in each plot. The height was measured vertically from the base of the plant to the growing tip, average was worked out and expressed in cm.

3.4.1.1.2 Number of Branches per Plant

The number of branches was counted from the tagged plants at 30 days interval and mean was taken as the number of branches per plant.

3.4.1.1.3 Plant Spread

Plant spread in observation plants was measured in the north-south and east-west direction at 30 days interval and the average was computed and expressed in cm.

3.4.1.1.4 Number of Leaves per Plant

The average number of leaves on the observation plants counted at 45 days interval was noted as number of leaves per plant.

3.4.1.1.5 Leaf Area

Leaf area was estimated at 45 days interval by employing linear measurement method length x breadth x constant (0.727) as suggested by Ravi *et al*. (2011) for Chinese potato. The length of leaf was measured from the point of petiole attachment to the leaf apex, and breadth, across the margin at maximum width. The total number of leaves was counted and multiplied with individual leaf area to record leaf area per plant.

3.4.1.2 Physiological and Biochemical parameters

3.4.1.2.1 Dry Matter Production

Dry matter production (DMP) was recorded at 45 days interval (45, 90 and 135 DAP). Sample plants were uprooted, separated into leaves, stem and tubers (whenever present) and weighed. From each plant part, subsamples were drawn for estimating dry weight. The subsamples were dried in hot air oven (70 ± 5°C) to constant dry weights and were used to compute the total DMP and expressed in t ha^{-1}.

3.4.1.2.2 Crop Growth Rate

The dry matter accumulation rate per unit plant area, CGR, was computed using the equation proposed by Watson (1952) and expressed as g m^{-2} day^{-1}.

$$\text{CGR} = \frac{(W_2 - W_1)}{(t_2 - t_1)} \times \frac{1}{A}$$

where,

W_1 - Dry weight of plant (g) at time t_1

W_2 - Dry weight of plant (g) at time t_2

A - Land area (m^2)

3.4.1.2.3 Relative Growth Rate

Relative Growth Rate (RGR) refers to the rate of increase in the dry weight of a crop plant in relation to its initial dry weight. The values were calculated using the formula given by Williams (1946) and expressed as g g^{-1} day^{-1}.

$$\text{RGR} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

where,

W_2 and W_1- Plant dry weights at time t_2 and t_1,

3.4.1.2.4 Leaf Area Index

Leaf area index was calculated as per the method suggested by Watson (1947).

$$\text{LAI} = \frac{\text{Leaf area per plant}}{\text{Land area occupied by the plant}}$$

3.4.1.2.5 Net Assimilation Rate

Net assimilation rate denotes the rate of increase in total dry weight per unit leaf area per unit time. It was calculated using the formula given by Williams (1946) and expressed in g cm^{-2} day^{-1}.

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e L_2 - \log_e L_1}{L_2 - L_1}$$

where,

L_2 and L_1 - Leaf area at time, t_2 and t_1 respectively
W_2 and W_1 - Plant dry weights at time, t_2 and t_1 respectively

3.4.1.2.6 Chlorophyll Content

The total chlorophyll content at flowering was estimated in the fully opened second leaf from the top as per the procedure described by Arnon (1949). Chlorophyll content was expressed in mg g^{-1} of fresh weight (FW) of leaf.

$$\text{Total chlorophyll} = 8.02\ A_{663} + 20.20\ A_{645} \times \frac{V}{1000 \times W}$$

where,

A- Absorbance at specific wavelengths
V- Final volume (mL) of chlorophyll extract in 80 per cent acetone
W- Fresh weight (g) of tissue extracted in 80 per cent acetone

3.4.1.2.7 Sucrose Content

Sucrose content of the tubers on fresh weight basis was analysed following the anthrone colorimetric method (Kang *et al.*, 2009). Extraction was done as per the procedure given by Xue (1985) and modified by Sharkar *et al.* (2019). Fresh tuber flesh (500 mg) was extracted with ethanol (80% v/v) thrice, 5 mL each time and the extracts were centrifuged at 5000 rpm for 10 minutes. The supernatants were combined in a 50 mL beaker and placed in a water bath at 80-85°C until the volume was reduced to 1 mL. The extract was made up to 10 mL with distilled water. From this, 0.75 mL of extract was taken in a test tube, mixed with 0.25 mL of 2M KOH, and boiled for 10 minutes. It was then allowed to cool to room temperature. After cooling 5 mL anthrone reagent was added to the mixture and incubated at 40°C for 15 minutes. The absorbance was read at 510 nm after cooling. A series of known concentrations of sucrose solutions were prepared by pipetting 0, 0.2, 0.4 and 0.6 mL from a working standard (100 ppm) solution to plot the standard curve and the amount of sucrose (mg g^{-1} FW) present in the sample was assessed, based on the absorbance read, from the curve.

3.4.1.2.8 Days to Senescence

The number of days taken by 50 per cent of the plants to exhibit senescence in each plot was visually observed and recorded.

3.4.1.2.9 Biomass Partitioning at the Start of Senescence

The biomass partitioning in the plants was assessed at the start of senescence. Plants were uprooted and separated into leaves, stem and tubers and the samples were dried in a hot air oven at 70±5°C to a constant dry weight. The weight of each plant part was recorded and biomass partitioning to the plant parts was expressed in percentage.

3.4.1.3 Yield Attributes and Yield

3.4.1.3.1 Number of Tubers per Plant

The number of tubers harvested in each observational plant were counted and averaged.

3.4.1.3.2 Average Tuber Weight

Tubers from observational plants were pooled, ten tubers were selected randomly, weighed and the average was worked out and expressed in g.

3.4.1.3.3 Tuber Yield per Plant

The tubers harvested from the tagged plants were weighed and the average was computed to get tuber yield per plant. The per plant yields were expressed in g.

3.4.1.3.4 Marketable Tuber Yield per Plant

Tubers in each observation plant were graded based on the individual weights into marketable (> 5 g) and less marketable (< 5 g) tubers, and the former were weighed separately to compute the marketable tuber yield per plant.

3.4.1.3.5 Percentage Marketable Tubers per Plant

Percentage marketable tubers per plant was calculated based on the number of marketable tubers and total number of tubers harvested in the observation plants.

3.4.1.3.6 Tuber Yield ha^{-1}

The tubers from the net plot area were weighed and yields expressed in t ha^{-1}.

3.4.1.3.7 Marketable Tuber Yield ha^{-1}

The marketable tubers from the net plot area were segregated, weighed expressed in t ha^{-1}. The percentages of marketable tuber yield were also computed.

3.4.1.3.8 Harvest Index

Harvest index was computed at the start of senescence using the formula given by Donald and Hamblin (1976).

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.4.1.4 Quality Attributes of Tuber

3.4.1.4.1 Starch

The titrimetric method suggested by Aminoff *et al*. (1970) was used for the estimation of starch content in tuber (%) on dry weight basis.

3.4.1.4.2 Protein Content

Protein content in tubers was computed by multiplying the N content in the tuber with a factor of 6.25 (Simpson *et al*., 1965). The values were expressed as percentage protein content on dry weight basis.

3.4.1.5 Plant Analysis

3.4.1.5.1 Uptake of NPK

Samples collected at the start of senescence were initially air dried and then oven dried at 70±5^{o}C to a constant weight. The nutrient contents of shoot and tubers were analysed separately. Dried samples were powdered and digested (sulphuric acid with digestion mixture for N and nitric-per chloric acid digestion

(9:4) for P and K) for the estimation of NPK content. The standard procedures adopted were, microkjeldahl digestion and distillation method for N (Jackson, 1973), spectrophotometry using vanadomolybdo phosphoric yellow colour method for P (Piper, 1966) and flame photometry for K (Piper, 1966).

3.4.1.6 Soil Analysis

Composite soil samples were collected from the field after the experiments in the two years from a depth of 15 cm. Samples were dried under shade, cleaned, sieved and subjected to chemical analysis. The soil pH and available NPK status were analysed in samples sieved through 2 mm sieve and organic carbon, through 0.2 mm sieve. Fresh soil samples collected from rhizosphere soil were used for the enumeration of microbes (bacteria, fungi and actinomycetes) and dehydrogenase activity. The procedures followed for analyses are furnished in Table 2.

3.4.1.7 Pest and Disease Incidence

Incidence of pests and diseases was monitored during the experimental period.

3.4.1.8 Economic Analysis

Economics of cultivation in terms of cost of cultivation and gross returns were calculated using prevailing wages, market prices of inputs and outputs. The market price of Chinese potato tubers and various inputs are given in Appendix V. The net returns and benefit-cost ratio (B: C ratio) were computed using the following formulae

$$\text{Net returns } (₹\ \text{ha}^{-1}) = \text{Gross returns } (₹\ \text{ha}^{-1}) - \text{Cost of cultivation } (₹\ \text{ha}^{-1})$$

$$\text{Benefit-cost ratio (B: C ratio)} = \frac{\text{Gross returns } (₹\ \text{ha}^{-1})}{\text{Cost of cultivation } (₹\ \text{ha}^{-1})}$$

3.4.1.9 Statistical Analysis

The data generated were statistically analysed using the technique of analysis of variance (ANOVA) for split plot design and the significance was tested by F test (Cochran and Cox, 1965). Wherever F test was found to be significant, critical differences were calculated. Data on percentage biomass partitioning were subjected to arc sine transformation. Pooled analysis was done for tuber yields in Experiment I based on the data of the two years and in economic analysis, the average mean of net returns and B:C ratios were computed.

Experiment II

3.4.2.1 Microclimate

The microclimatic parameters in the trenches and in the open were recorded at 7.30 am weekly intervals.

3.4.2.1.1 CO_2 Release

Carbon dioxide release from the organic substrate in the trench was recorded using GE Telaire ® 7001 CO_2/Temperature monitor (GE sunsing, USA) and expressed in ppm.

3.4.2.1.2 Soil Temperature

The soil temperature (^oC) at 5 cm depth was measured using Probe type digital thermometer (Divinest TP 101, India).

3.4.2.1.3 Air Temperature

The air temperature (°C) was measured using GE Telaire ® 7001 CO_2/ Temperature monitor (GE sunsing, USA) used for measuring CO_2 release.

3.4.2.2 Biometric and Yield Observations

The observations from tagged plants were recorded adopting the methods described in experiment I.

The growth attributes, plant height, number of branches per plant, number of leaves per plant and leaf area per plant were recorded at 30 days interval. Chlorophyll content in leaves was estimated at 45 days interval as per the procedure mentioned in section 3.4.1.2.6. The number of days to senescence and biomass partitioning at the start of senescence were recorded. Uptake of NPK per plant was computed based on nutrient content and DMP.

3.4.2.3 Pest and Disease Incidence

Pest and disease incidence in the plants was monitored and noted.

3.4.2.4 Substrate Analysis

3.4.2.4.1 C: N Ratio of Substrate

Composite samples of the substrates were taken from the soil surface in trenches after the harvest of crop. Organic C content of the substrates was analysed adopting the standard procedure (Table 2) and N, by microkjeldahl digestion and distillation method (Jackson, 1973). The ratio of organic C to N was calculated and presented as C: N ratio.

3.4.2.5 Soil Analysis

Organic C content of soil/potting mixture was analysed after experiment as per the standard procedure given in Table 2.

3.4.2.6 Statistical Analysis

The data generated were analysed statistically using the technique of analysis of variance (ANOVA) for completely randomized design and the significance was tested by F test (Cochran and Cox, 1965). Wherever F test was found significant, critical differences were calculated.

RESULTS

4. RESULTS

The field experiments related to the study on "Resource management for source-sink modulation in Chinese potato [*Plectranthus rotundifolius* (Poir.) Spreng.]" were conducted at Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram during 2019 - 2021. The data recorded were tabulated, analysed statistically and the results obtained are detailed in this chapter.

4.1 EXPERIMENT I: INFLUENCE OF METHOD OF PLANTING, NUTRIENT MANAGEMENT AND GROWTH PROMOTERS ON THE SOURCE - SINK RELATIONSHIP, TUBER YIELD AND QUALITY IN CHINESE POTATO

4.1.1 Growth Attributes

Growth characters *viz.* plant height, number of branches per plant and plant spread at 30 days interval, number of leaves per plant and leaf area at 45 days interval in Chinese potato as influenced by the treatments were recorded and presented in Tables 4 to 9.

4.1.1.1 Plant Height

The effect of the method of planting and nutrient management + growth promoter combination on plant height at 30 days interval during the two years of experimentation are presented in Tables 4a and 4b.

In the first year, significant variations in plant height were observed due to the method of planting and the combination of nutrient management and growth promoters. Plants were taller in the bed method of planting at a spacing of 30 cm x 15 cm (m_1) at 30 and 60 DAP (13.74 and 19.62 cm respectively) which was on par with the ridge method of planting at 30 cm x 15 cm spacing (m_3). At 90 DAP, the ridge method of planting at 30 cm x 15 cm (m_3) recorded the tallest plants (19.91 cm) and was on par with the bed method with cuttings planted at spacings, 30 cm x 30 cm and 30 cm x 15 cm (m_2 and m_1 respectively). At 120 DAP, the significantly tallest plants were observed in m_1 (25.09 cm).

Perusal of the data on sub plot effects revealed that, at 30 DAP, the treatment combination, 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA (n_1g_2) showed significantly taller plants (13.63 cm) which was on par with 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) and 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + water spray (n_1g_3). The treatment combination n_1g_1 produced the significantly tallest plants at 60, 90 and 120 DAP (20.26 cm, 23.07 cm, and 26.36 cm respectively).

Interaction effect was significant only at 60 DAP, plants being the tallest (22.19 cm) in the treatment combination $m_1n_1g_1$. The shortest plants at 60 DAP were observed in the treatment combination $m_5n_2g_3$.

During the second year, plants were significantly the tallest (15.51 cm, 21.46 cm, 24.59 cm and 26.70 cm) in m_1 (bed method of planting at 30 cm x 15 cm) at all the stages and on par with m_3 (ridge method of planting at 30 cm x 15 cm spacing). In the case of nutrient management + growth promoter effect, maximum plant height (15.55 cm) was observed with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) and it was on par with n_1g_2 and n_1g_3 (15.51 cm and 15.49 cm respectively). As in the first year, the significantly highest plant heights were recorded in n_1g_1 (22.40 cm, 25.61 cm and 27.77 cm) at 60, 90 and 120 DAP, respectively.

The interaction effect on plant height was significant at all the stages of growth. At 30 DAP, bed method of planting at 30 cm x 15 cm, along with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA ($m_1n_1g_2$) resulted in a higher plant height (17.00 cm) and was on par with $m_1n_1g_1$, $m_1n_1g_3$, $m_3n_1g_1$, $m_3n_1g_2$, and $m_3n_1g_3$. At 60 and 90 DAP, taller plants were produced by the treatment combination $m_1n_1g_1$, which remained on par with $m_1n_1g_2$ and $m_3n_1g_1$. At 120 DAP, plant height (29.85 cm) was maximum in $m_1n_1g_1$ on par with $m_3n_1g_1$.

Table 4a. Effect of method of planting and nutrient management x growth promoter on plant height, cm

Treatments	Plant height							
	2019-20				2020-21			
	30 DAP	60 DAP	90 DAP	120 DAP	30 DAP	60 DAP	90 DAP	120 DAP
Method of planting								
m_1 - Bed method (30 cm x 15 cm)	13.74	19.62	19.23	25.09	15.51	21.46	24.59	26.70
m_2 - Bed method (30 cm x 30 cm)	12.87	17.88	19.68	23.67	14.30	19.90	22.72	24.47
m_3 - Ridge method (30 cm x 15 cm)	13.58	18.95	19.91	24.43	15.42	20.90	23.90	26.00
m_4 - Ridge method (30 cm x 30 cm)	12.29	17.82	17.32	23.12	14.51	19.78	22.65	24.56
m_5 - Mound method (30 cm x 30 cm)	11.56	17.53	18.82	23.41	14.38	19.46	22.29	24.09
SEm (±)	0.28	0.31	0.23	0.15	0.25	0.26	0.24	0.23
CD (0.05)	0.857	0.948	0.715	0.475	0.764	0.798	0.731	0.705
Nutrient management x growth promoter								
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	13.61	20.26	23.07	26.36	15.55	22.40	25.61	27.77
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	13.63	19.40	21.94	25.25	15.51	21.50	24.63	26.70
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	13.50	18.54	21.07	24.15	15.49	20.56	23.56	25.54
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	11.96	18.00	20.58	23.55	14.01	19.82	22.70	24.51
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	12.03	17.19	20.01	22.56	14.20	19.08	21.85	23.70
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	12.12	16.76	18.99	21.77	14.18	18.45	21.04	22.76
SEm (±)	0.21	0.20	0.30	0.27	0.23	0.20	0.21	0.25
CD (0.05)	0.590	0.573	0.836	0.755	0.643	0.573	0.590	0.700

Table 4b. Interaction effect of method of planting and combination of nutrient management + growth promoter on plant height, cm

Treatments	Plant height							
	2019-20				2020-21			
	30 DAP	60 DAP	90 DAP	120 DAP	30 DAP	60 DAP	90 DAP	120 DAP
$m_1n_1g_1$	15.02	22.19	25.38	27.86	16.83	23.83	27.30	29.85
$m_1n_1g_2$	14.85	20.69	23.13	26.53	17.00	22.69	26.00	28.19
$m_1n_1g_3$	15.25	19.87	22.26	25.52	16.62	21.83	25.01	27.12
$m_1n_2g_1$	12.33	19.85	21.57	25.09	14.08	21.46	24.58	26.65
$m_1n_2g_2$	12.51	17.84	20.95	23.15	14.25	19.80	22.68	24.59
$m_1n_2g_3$	12.48	17.27	19.23	22.41	14.25	19.17	21.96	23.81
$m_2n_1g_1$	13.71	19.16	23.08	25.86	14.28	21.35	24.46	25.77
$m_2n_1g_2$	13.68	18.37	21.67	24.57	13.92	20.50	23.49	25.46
$m_2n_1g_3$	13.14	17.96	20.98	24.03	14.00	20.05	22.97	24.90
$m_2n_2g_1$	11.97	17.15	20.73	23.42	14.37	19.03	21.80	23.64
$m_2n_2g_2$	12.19	16.80	20.16	22.10	14.58	18.65	21.37	23.17
$m_2n_2g_3$	12.55	17.82	19.68	22.01	14.67	19.83	22.25	23.87
$m_3n_1g_1$	14.35	20.73	23.72	27.22	16.38	23.28	26.42	29.15
$m_3n_1g_2$	14.91	20.05	22.45	26.01	16.45	22.25	25.49	27.64
$m_3n_1g_3$	14.52	18.54	21.74	24.06	16.58	20.58	23.58	25.57
$m_3n_2g_1$	12.92	18.62	21.20	23.87	14.75	20.42	23.39	25.36
$m_3n_2g_2$	12.33	18.09	20.59	23.48	14.08	20.08	23.01	24.95
$m_3n_2g_3$	12.48	17.66	19.91	21.94	14.25	18.77	21.50	23.31
$m_4n_1g_1$	12.75	19.41	22.05	25.14	15.08	21.50	24.63	26.71
$m_4n_1g_2$	12.54	18.85	21.63	24.46	15.08	20.92	23.96	25.98
$m_4n_1g_3$	12.76	18.24	20.18	23.67	15.00	20.25	23.20	25.15
$m_4n_2g_1$	12.08	17.59	19.70	22.82	13.67	19.52	22.36	24.24
$m_4n_2g_2$	11.77	16.94	19.23	21.98	13.92	18.80	21.54	23.35
$m_4n_2g_3$	11.84	15.92	17.32	20.66	14.33	17.67	20.24	21.94
$m_5n_1g_1$	12.25	19.84	21.12	25.74	15.17	22.02	25.22	27.35
$m_5n_1g_2$	12.18	19.04	20.81	24.70	15.08	21.13	24.21	26.25
$m_5n_1g_3$	11.81	18.10	20.18	23.49	15.25	20.09	23.02	24.96
$m_5n_2g_1$	10.50	16.80	19.70	22.56	13.17	18.65	21.37	22.67
$m_5n_2g_2$	11.37	16.26	19.11	22.09	14.17	18.05	20.68	22.42
$m_5n_2g_3$	11.23	15.15	18.82	21.85	13.42	16.82	19.27	20.89
SEm (±)	0.51	0.52	0.65	0.57	0.53	0.49	0.49	0.56
CD (0.05)	NS	1.281	NS	NS	1.439	1.281	1.319	1.566

The lowest plant height was recorded in $m_5n_2g_1$ at 30 DAP and in $m_5n_2g_3$, at later stages of observation.

4.1.1.2 Number of Branches per Plant

The data on the number of branches per plant as influenced by the method of planting and nutrient management x growth promoter combination at 30 days intervals are shown in Tables 5a and 5b.

At 30 DAP, the number of branches per plant varied significantly during the first year but remained comparable in the second year for the main plot effect. In the first year, bed and ridge methods of planting at 30 cm x 30 cm spacing (m_2 and m_4) recorded higher number of branches per plant (13.2) and were on par with the mound method at 30 cm x 30 cm spacing (m_5). At 60 and 90 DAP, bed method of planting at 30 cm x 30 cm spacing (m_2) recorded the higher number of branches and was on par with the ridge method at 30 cm x 30 cm spacing (m_4) during both years. At 120 DAP also, the higher number of branches observed in m_2 and was on par with m_4 and m_5 during the first year and with m_4 during the second year.

The sub plot effect was significant at 30 DAP alone during first year and higher number of branches (13.2) was produced with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1), on par with n_1g_2 and n_1g_3. At 60 and 90 DAP, n_1g_1 produced the significantly highest number of branches per plant during both years. Whereas at 120 DAP, the variations were significant in the second year alone and the treatment n_1g_1 produced the maximum number of branches per plant (10.9).

Analysing the interaction effects, the number of branches per plant was found to vary significantly at 60 and 90 DAP in the first year and at 60, 90 and 120 DAP in the second year. In general, $m_2n_1g_1$ proved superior. During the first year, number of branches per plant was the highest in $m_2n_1g_1$ (20.9) and on par with $m_2n_1g_2$ (19.3) and $m_4n_1g_1$ (19.6) at 60 DAP. In the second year, the treatment combinations $m_2n_1g_1$ and $m_4n_1g_1$ were on par (21.7 and 20.3 respectively). The trend remained similar at 90 DAP in both years. At this stage, a higher number of branches per plant was recorded in $m_2n_1g_1$ (22.0) and was on par with $m_4n_1g_1$ (20.8) in the first and second year (22.5). There was a decreasing trend in the number of branches towards harvest. At 120 DAP, during the second year per plant branches were the highest in $m_2n_1g_1$ (12.0).

4.1.1.3 Plant Spread (North- South)

The effect of method of planting and nutrient management x growth promoter combination on plant spread (N-S) at 30 days interval in two years are presented in Tables 6a and 6b. Plant spread increased gradually as growth advanced upto 90 DAP and thereafter it decreased in both the years.

Perusal of the data in Table 6a revealed that the plant spread (N-S) varied markedly with the method of planting and the nutrient management x growth promoter combination in both the years. In the first year, the significantly highest plant spread (25.23 cm, 34.34 cm, 35.39 cm and 22.21 cm) was observed in ridge method of planting at 30 cm x 30 cm spacing (m_4) at 30, 60, 90 and 120 DAP. During the second year also, the N-S plant spread (26.33 cm) was maximum in m_4 and on par with bed method of planting at 30 cm x 30 cm spacing (m_2) at 30 DAP. The trend was similar in the second year with m_4 being on par with m_2 at 60, 90 and 120 DAP, the maximum values being 33.66 cm, 35.73 cm and 21.76 cm respectively in m_4.

Among the subplot effects, irrespective of the growth promoter used, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 evinced higher plant spread in N-S direction at 30 DAP in both the years. At 30 DAP, higher plant spread (24.82 cm) observed in n_1g_3 was on par with n_1g_1 and n_1g_2 during first year. In the second year, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA (n_1g_2) produced the highest plant spread (26.35 cm) and was on par with n_1g_1 and n_1g_3. At 60, 90 and 120 DAP, maximum spreads were observed with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) during both the years

Table 5a. Effect of method of planting and nutrient management x growth promoter on number of branches per plant

Treatments	Number of branches per plant							
	2019-20				2020-21			
	30 DAP	60 DAP	90 DAP	120 DAP	30 DAP	60 DAP	90 DAP	120 DAP
Method of planting								
m_1 - Bed method (30 cm x 15 cm)	12.7	16.9	18.0	10.0	14.5	17.1	17.7	9.5
m_2 - Bed method (30 cm x 30 cm)	13.2	18.0	19.0	10.9	14.3	18.9	19.6	10.4
m_3 - Ridge method (30 cm x 15 cm)	12.1	16.8	17.7	9.9	14.4	17.0	17.7	9.4
m_4 - Ridge method (30 cm x 30 cm)	13.2	17.8	18.8	10.8	14.6	18.4	19.2	10.2
m_5 - Mound method (30 cm x 30 cm)	12.8	16.7	17.7	10.5	14.3	18.0	18.7	10.0
SEm (±)	0.13	0.17	0.18	0.17	0.11	0.16	0.21	0.08
CD (0.05)	0.401	0.510	0.559	0.527	NS	0.507	0.647	0.247
Nutrient management x growth promoter								
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	13.2	18.7	19.8	10.7	14.5	19.7	20.5	10.9
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	13.0	17.8	18.7	10.5	14.5	18.7	19.4	10.4
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	12.8	17.6	18.5	10.3	14.4	18.0	18.7	10.0
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	12.6	16.8	17.8	10.3	14.4	17.6	18.2	9.7
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	12.5	16.6	17.6	10.3	14.6	17.1	17.7	9.5
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	12.6	16.0	17.0	10.3	14.3	16.2	16.8	9.0
SEm (±)	0.17	0.29	0.23	0.13	0.17	0.15	0.20	0.11
CD (0.05)	0.473	0.804	0.649	NS	NS	0.431	0.560	0.316

Table 5b. Interaction effect of method of planting and combination of nutrient management + growth promoter on number of branches per plant

Treatments	Number of branches per plant							
	2019-20				2020-21			
	30 DAP	60 DAP	90 DAP	120 DAP	30 DAP	60 DAP	90 DAP	120 DAP
$m_1n_1g_1$	13.3	18.1	19.1	10.0	14.8	18.8	19.6	10.4
$m_1n_1g_2$	13.2	17.2	18.2	9.9	14.2	18.5	19.2	10.2
$m_1n_1g_3$	13.3	18.0	19.0	10.0	14.5	17.2	17.9	9.5
$m_1n_2g_1$	12.0	16.4	17.3	9.9	14.6	16.8	17.5	9.3
$m_1n_2g_2$	12.3	16.4	17.5	10.1	14.9	16.4	17.0	9.1
$m_1n_2g_3$	12.2	15.5	16.5	10.0	14.1	14.8	15.4	8.2
$m_2n_1g_1$	13.8	20.9	22.0	11.5	14.7	21.7	22.5	12.0
$m_2n_1g_2$	13.1	19.3	20.4	10.8	14.4	19.8	20.5	10.9
$m_2n_1g_3$	12.9	18.6	19.7	10.6	14.3	19.0	19.7	10.5
$m_2n_2g_1$	12.9	16.9	17.9	10.6	14.0	18.4	19.1	10.2
$m_2n_2g_2$	13.2	16.4	17.4	10.8	14.2	17.9	18.6	9.9
$m_2n_2g_3$	13.1	16.0	17.0	10.8	14.3	16.4	17.0	9.1
$m_3n_1g_1$	12.7	16.8	17.9	10.5	14.5	18.0	18.7	10.0
$m_3n_1g_2$	12.5	16.2	17.1	10.3	14.3	17.8	18.5	9.8
$m_3n_1g_3$	11.8	15.9	16.9	9.7	14.7	17.2	17.9	9.5
$m_3n_2g_1$	12.0	17.2	18.2	9.8	14.3	16.8	17.5	9.3
$m_3n_2g_2$	11.6	17.5	18.2	9.5	14.6	16.3	16.9	9.0
$m_3n_2g_3$	11.8	17.1	18.0	9.7	14.2	16.1	16.7	8.9
$m_4n_1g_1$	13.4	19.6	20.8	11.0	14.0	20.3	21.0	11.2
$m_4n_1g_2$	13.3	18.8	19.7	10.9	14.7	19.2	19.9	10.6
$m_4n_1g_3$	13.3	18.3	19.1	10.9	14.9	18.6	19.3	10.3
$m_4n_2g_1$	13.1	17.7	18.7	10.8	14.8	18.1	18.8	10.0
$m_4n_2g_2$	12.9	16.9	17.9	10.6	14.7	17.6	18.3	9.7
$m_4n_2g_3$	13.0	15.8	16.8	10.7	14.6	17.0	17.7	9.4
$m_5n_1g_1$	13.0	18.2	19.3	10.7	14.7	19.7	20.5	10.9
$m_5n_1g_2$	13.1	17.3	18.3	10.7	14.9	18.5	19.2	10.2
$m_5n_1g_3$	12.8	17.0	17.8	10.5	13.5	17.9	18.6	9.9
$m_5n_2g_1$	12.7	15.8	16.8	10.5	14.2	17.7	18.4	9.8
$m_5n_2g_2$	12.4	16.0	17.1	10.2	14.4	17.2	17.9	9.5
$m_5n_2g_3$	12.7	15.6	16.7	10.4	14.2	16.8	17.4	9.3
SEm (±)	0.4	0.6	0.5	0.3	0.4	0.4	0.5	0.2
CD (0.05)	NS	1.80	1.45	NS	NS	0.97	1.25	0.71

Table 6a. Effect of method of planting and nutrient management x growth promoter on plant spread (North-South), cm

Treatments	Plant spread (North-South)							
	2019-20				2020-21			
	30 DAP	60 DAP	90 DAP	120 DAP	30 DAP	60 DAP	90 DAP	120 DAP
Method of planting								
m_1 - Bed method (30 cm x 15 cm)	22.12	31.02	32.02	19.97	24.17	30.41	32.24	19.66
m_2 - Bed method (30 cm x 30 cm)	23.82	33.58	34.49	21.70	26.14	32.91	34.90	21.28
m_3 - Ridge method (30 cm x 15 cm)	23.39	31.12	32.08	20.12	24.62	30.50	32.38	19.72
m_4 - Ridge method (30 cm x 30 cm)	25.23	34.34	35.39	22.21	26.33	33.66	35.73	21.76
m_5 - Mound method (30 cm x 30 cm)	23.32	32.72	33.73	21.15	24.37	32.07	34.00	20.73
SEm (±)	0.40	0.41	0.22	0.17	0.24	0.35	0.32	0.22
CD (0.05)	1.233	1.265	0.676	0.523	0.75	1.091	0.992	0.679
Nutrient management x growth promoter								
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	24.81	35.86	36.87	23.17	26.26	35.15	37.37	22.72
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	24.71	34.10	35.16	21.98	26.35	33.43	35.44	21.61
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	24.82	32.75	33.76	21.17	26.26	32.10	34.03	20.75
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	22.32	31.99	32.98	20.68	23.75	31.36	33.25	20.27
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	22.31	31.10	32.06	20.10	24.09	30.49	32.32	19.71
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	22.49	29.52	30.43	19.08	24.05	28.94	30.68	18.71
SEm (±)	0.37	0.40	0.38	0.26	0.30	0.45	0.38	0.26
CD (0.05)	1.034	1.116	1.073	0.735	0.835	1.269	1.079	0.722

Table 6b. Interaction effect of method of planting and combination of nutrient management + growth promoter on plant spread (North-South), cm

Treatments	Plant spread (North-South)							
	2019-20				2020-21			
	30 DAP	60 DAP	90 DAP	120 DAP	30 DAP	60 DAP	90 DAP	120 DAP
$m_1n_1g_1$	22.91	32.82	34.09	21.08	23.72	32.17	34.11	20.80
$m_1n_1g_2$	22.05	32.35	33.35	20.57	23.60	31.71	33.62	20.50
$m_1n_1g_3$	22.93	31.37	32.33	20.28	23.74	30.75	32.60	19.88
$m_1n_2g_1$	21.94	30.62	31.57	19.80	24.36	30.02	31.82	19.40
$m_1n_2g_2$	21.09	29.71	30.63	19.21	24.73	29.12	30.88	18.83
$m_1n_2g_3$	21.79	29.26	30.16	18.91	24.87	28.68	30.40	18.54
$m_2n_1g_1$	24.53	36.87	37.26	23.83	27.78	36.14	38.31	23.36
$m_2n_1g_2$	25.44	34.90	35.97	22.56	27.89	34.21	36.27	22.12
$m_2n_1g_3$	24.91	33.78	34.83	21.84	28.12	33.12	35.12	21.41
$m_2n_2g_1$	22.66	32.95	33.97	21.30	25.01	32.30	34.25	20.88
$m_2n_2g_2$	22.57	32.01	33.00	20.69	23.88	31.38	33.27	20.28
$m_2n_2g_3$	22.84	30.95	31.91	20.00	24.16	30.34	32.16	19.61
$m_3n_1g_1$	24.20	34.28	35.34	22.16	25.57	33.60	35.88	21.72
$m_3n_1g_2$	24.04	33.63	34.67	21.74	25.67	32.96	34.95	21.31
$m_3n_1g_3$	24.56	31.37	32.33	20.28	25.43	30.75	32.60	19.88
$m_3n_2g_1$	22.38	30.62	31.57	19.80	23.17	30.02	31.82	19.40
$m_3n_2g_2$	22.46	29.89	30.81	19.32	23.60	29.30	31.07	18.94
$m_3n_2g_3$	22.72	26.93	27.76	17.41	24.30	26.39	27.98	17.06
$m_4n_1g_1$	27.57	39.45	40.67	25.60	28.54	38.67	41.25	25.00
$m_4n_1g_2$	27.30	35.95	37.07	23.25	29.04	35.24	37.37	22.78
$m_4n_1g_3$	26.71	34.61	35.67	22.37	28.17	33.92	35.97	21.93
$m_4n_2g_1$	23.07	33.54	34.57	21.68	23.88	32.87	34.85	21.25
$m_4n_2g_2$	23.38	32.57	33.57	21.05	24.21	31.92	33.85	20.64
$m_4n_2g_3$	23.34	29.89	30.81	19.32	24.16	29.30	31.07	18.94
$m_5n_1g_1$	24.84	35.89	36.99	23.19	25.72	35.17	37.29	22.74
$m_5n_1g_2$	24.70	33.68	34.72	21.77	25.57	33.01	35.00	21.34
$m_5n_1g_3$	24.98	32.60	33.61	21.08	25.86	31.96	33.89	20.66
$m_5n_2g_1$	21.56	32.22	33.22	20.83	22.32	31.59	33.49	20.42
$m_5n_2g_2$	22.08	31.33	32.30	20.25	24.02	30.71	32.56	19.85
$m_5n_2g_3$	21.78	30.58	31.53	19.77	22.75	29.98	31.79	19.38
SEm (±)	0.85	0.91	0.81	0.56	0.65	0.98	0.84	0.57
CD (0.05)	NS	NS	NS	NS	1.867	NS	NS	NS

(35.86 cm, 36.87 cm and 23.17 cm in the first year and 35.15 cm, 37.37 cm and 22.72 cm in the second year respectively).

The interaction effect of method of planting and combination of nutrient management x growth promoter was non significant in the first year at all stages of growth. However, in the second year, significant variation was recorded at 30 DAP, and the highest plant spread (29.04 cm) was recorded in ridge method of planting at 30 cm x 30 cm spacing along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA ($m_4n_1g_2$). The effect was on par with $m_4n_1g_1$, $m_4n_1g_3$, $m_2n_1g_1$, $m_2n_1g_2$ and $m_2n_1g_3$.

4.1.1.4 Plant Spread (East- West)

The variations in plant spread in E-W direction due to the effects of methods of planting and combination of nutrient management and growth promoter in the two experiments are presented in Tables 7a and 7b.

The methods of planting and combination of nutrient management and growth promoter exerted significant influence on the plant spread in E-W direction in all the stages with m_4 being superior. Similar to the plant spread in N-S direction, the spread in E-W direction also increased until 90 DAP and thereafter decreased towards harvest. In both the years, at 30 DAP, Chinese potato planted on ridges at 30 cm x 30 cm spacing (m_4) had higher plant spreads (28.89 cm and 28.02 cm respectively) and was on par with bed planting at 30 cm x 30 cm spacing (m_2). At 60 DAP, m_4 produced the maximum plant spread and was on par with m_2 and m_5 in the first year, and in the second year, it was significantly the highest (34.96 cm) in m_4 (ridge method of planting at 30 cm x 30 cm spacing). At 90 DAP, m_4 was on par with m_2 in both the years. In the first year, at 120 DAP, m_4 (25.98 cm) was on par with m_5 (25.19 cm) and m_2 (25.45 cm). In the second year, m_4 and m_2 were on par (24.90 cm and 24.35 cm respectively).

The significant influence of nutrient management + growth promoter combination was evident in both the years. At 30 DAP, irrespective of the growth promoter used, all the treatments involving 60:30:120 kg NPK ha^{-1} and PGPR Mix 1 recorded higher plant spread in both the years and were on par. At 60, 90 and 120 DAP, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) recorded the significantly highest plant spread in both the years (37.34, 37.72 and 27.33 cm in the first year and 36.51, 38.18 and 26.01 cm in the second year respectively).

The interaction failed to bring about a significant effect in the first year at any of the growth stages assessed. But in the second year, at 30 DAP, spread was the highest in plants grown on ridges at 30 cm x 30 cm spacing along with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA ($m_4n_1g_2$) and on par with $m_4n_1g_1$, $m_4n_1g_3$, $m_2n_1g_1$, $m_2n_1g_2$ and $m_2n_1g_3$.

4.1.1.5 Number of Leaves per Plant

The number of leaves per plant was maximum at 45 DAP and thereafter declined. The effects of method of planting and combination of nutrient management and growth promoter on the number of leaves per plant at 45 days interval are depicted in Table 8a and 8b. At 135 DAP, the number of leaves were very low as the plants were in the senescent stage.

The highest number of leaves per plant was observed in m_2 at all the stages of observation during both the years. Among the sub plot treatments, irrespective of the growth promoter used, n_1 (60:30:120 kg NPK ha^{-1} + PGPR Mix 1) was found to yield higher number of leaves at 45 DAP during both years. Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) recorded higher number of leaves (70.4 and 72.2) during the both the years. At 135 DAP, n_1g_2 and n_2g_2 recorded higher number of leaves in the first year (12.3 and 12.0) and second year (11.3 and 10.8), respectively.

Perusal of data in Table 8b revealed the significant variations with the interactions of methods of planting and nutrient management + growth promoter combination on number of leaves per plant.

Table 7a. Effect of method of planting and nutrient management x growth promoter on plant spread (East-West), cm

Treatments	Plant spread (East-West)							
	2019-20				2020-21			
	30 DAP	60 DAP	90 DAP	120 DAP	30 DAP	60 DAP	90 DAP	120 DAP
Method of planting								
m_1 - Bed method (30 cm x 15 cm)	26.47	32.26	32.54	23.60	25.66	31.59	33.03	22.50
m_2 - Bed method (30 cm x 30 cm)	28.72	34.90	35.13	25.45	27.65	34.19	35.75	24.35
m_3 - Ridge method (30 cm x 15 cm)	27.05	32.34	32.60	23.59	26.03	31.69	33.13	22.57
m_4 - Ridge method (30 cm x 30 cm)	28.89	35.68	35.96	25.98	28.02	34.96	36.55	24.90
m_5 - Mound method (30 cm x 30 cm)	26.65	34.37	34.23	25.19	25.78	33.31	34.83	23.73
SEm (±)	0.52	0.45	0.30	0.26	0.24	0.50	0.36	0.34
CD (0.05)	1.592	1.388	0.936	0.813	0.745	1.546	1.118	1.057
Nutrient management x growth promoter								
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	28.84	37.34	37.72	27.33	27.95	36.51	38.18	26.01
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	28.89	35.52	35.67	25.95	28.00	34.72	36.31	24.73
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	28.94	34.12	34.26	24.92	27.78	33.34	34.86	23.75
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	26.17	33.25	33.46	24.25	25.12	32.57	34.06	23.20
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	26.34	32.44	32.54	23.65	25.47	31.67	33.11	22.56
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	26.15	30.79	30.88	22.47	25.44	30.06	31.43	21.41
SEm (±)	0.45	0.44	0.41	0.32	0.35	0.48	0.50	0.30
CD (0.05)	1.266	1.238	1.164	0.893	0.978	1.362	1.411	0.846

Table 7b. Interaction effect of method of planting and combination of nutrient management + growth promoter on plant spread (East-West), cm

Treatments	Plant spread (East-West)							
	2019-20				2020-21			
	30 DAP	60 DAP	90 DAP	120 DAP	30 DAP	60 DAP	90 DAP	120 DAP
$m_1n_1g_1$	25.64	34.21	34.85	25.38	25.62	33.42	34.95	23.80
$m_1n_1g_2$	26.01	33.62	33.84	24.52	24.96	32.94	34.44	23.46
$m_1n_1g_3$	26.16	32.60	32.81	23.78	25.11	31.94	33.39	22.75
$m_1n_2g_1$	26.84	31.83	32.03	23.21	25.77	31.18	32.60	22.21
$m_1n_2g_2$	27.25	30.87	31.08	22.52	26.16	30.25	31.63	21.55
$m_1n_2g_3$	26.90	30.41	30.60	22.18	26.31	29.79	31.15	21.22
$m_2n_1g_1$	30.61	38.32	38.56	27.94	29.39	37.54	39.25	26.74
$m_2n_1g_2$	30.73	36.27	36.51	26.46	29.51	35.54	37.15	25.31
$m_2n_1g_3$	30.99	35.12	35.35	25.61	29.75	34.40	35.97	24.50
$m_2n_2g_1$	27.56	34.25	34.47	24.98	26.46	33.55	35.08	23.90
$m_2n_2g_2$	26.31	33.27	33.49	24.26	25.26	32.59	34.08	23.21
$m_2n_2g_3$	26.12	32.17	32.37	23.46	25.56	31.51	32.95	22.44
$m_3n_1g_1$	28.18	35.62	36.11	25.98	27.06	34.91	36.50	24.86
$m_3n_1g_2$	28.29	34.95	35.18	25.49	27.06	34.24	35.80	24.39
$m_3n_1g_3$	28.02	32.60	32.81	23.78	26.91	31.94	33.39	22.75
$m_3n_2g_1$	25.53	31.83	32.03	23.21	24.51	31.18	32.60	22.21
$m_3n_2g_2$	26.01	31.07	31.27	22.66	24.96	30.44	31.82	21.68
$m_3n_2g_3$	26.28	27.98	28.16	20.41	25.71	27.42	28.67	19.53
$m_4n_1g_1$	31.45	41.00	41.52	29.66	30.49	40.17	42.00	28.61
$m_4n_1g_2$	31.25	37.36	37.61	27.25	31.44	36.61	38.28	26.08
$m_4n_1g_3$	31.04	35.96	36.21	26.23	29.81	35.24	36.84	25.10
$m_4n_2g_1$	26.31	34.85	35.08	25.42	25.26	34.15	35.70	24.32
$m_4n_2g_2$	26.68	33.84	34.07	24.69	25.56	33.16	34.67	23.62
$m_4n_2g_3$	26.62	31.07	31.27	22.66	25.56	30.44	31.82	21.68
$m_5n_1g_1$	28.34	37.53	37.53	27.71	27.20	36.54	38.20	26.02
$m_5n_1g_2$	28.18	35.40	35.23	26.01	27.06	34.29	35.86	24.42
$m_5n_1g_3$	28.50	34.30	34.11	25.22	27.35	33.20	34.71	23.65
$m_5n_2g_1$	24.60	33.49	33.71	24.43	23.62	32.81	34.31	23.37
$m_5n_2g_2$	25.47	33.16	32.77	24.12	25.41	31.90	33.36	22.72
$m_5n_2g_3$	24.82	32.32	32.00	23.65	24.07	31.14	32.56	22.18
SEm (±)	1.05	1.00	0.90	0.70	0.75	1.11	1.08	0.70
CD (0.05)	NS	NS	NS	NS	2.186	NS	NS	NS

Table 8a. Effect of method of planting and nutrient management x growth promoter on number of leaves per plant

Treatments	Number of leaves per plant					
	2019-20			2020-21		
	45 DAP	90 DAP	135 DAP	45 DAP	90 DAP	135 DAP
Method of planting						
m_1 - Bed method (30 cm x 15 cm)	96.3	60.3	11.1	104.2	61.7	9.9
m_2 - Bed method (30 cm x 30 cm)	108.2	66.5	12.1	112.1	68.6	11.4
m_3 - Ridge method (30 cm x 15 cm)	93.9	57.4	10.8	103.2	59.0	10.0
m_4 - Ridge method (30 cm x 30 cm)	105.2	62.6	12.0	111.1	63.4	11.3
m_5 - Mound method (30 cm x 30 cm)	103.0	62.5	11.6	103.6	63.3	10.8
SEm (±)	0.8	0.7	0.3	0.9	0.6	0.3
CD (0.05)	2.55	2.06	NS	2.75	1.90	NS
Nutrient management x growth promoter						
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	105.6	70.4	11.4	111.4	72.2	10.7
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	105.5	65.9	12.3	112.5	66.3	11.3
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	105.0	60.3	11.5	111.6	60.7	10.7
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	97.5	62.6	11.0	100.9	64.3	10.3
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	96.7	58.8	12.0	102.3	61.7	10.8
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	97.4	53.2	11.1	102.2	53.8	10.3
SEm (±)	1.1	0.8	0.2	1.5	0.8	0.2
CD (0.05)	2.96	2.38	0.48	4.26	2.34	0.54

Table 8b. Interaction effect of method of planting and combination of nutrient management + growth promoter on number of leaves per plant

Treatments	Number of leaves per plant					
	2019-20			2020-21		
	45 DAP	90 DAP	135 DAP	45 DAP	90 DAP	135 DAP
$m_1n_1g_1$	100.8	67.1	10.9	106.2	67.9	9.8
$m_1n_1g_2$	101.2	64.5	11.5	108.7	63.8	10.2
$m_1n_1g_3$	99.8	57.3	11.0	108.1	59.3	9.9
$m_1n_2g_1$	93.1	65.1	10.7	98.5	67.0	9.7
$m_1n_2g_2$	91.6	54.9	11.8	100.3	59.1	10.3
$m_1n_2g_3$	91.3	52.9	10.9	103.3	53.0	9.9
$m_2n_1g_1$	116.9	77.5	11.8	122.5	80.0	11.1
$m_2n_1g_2$	118.3	72.0	13.5	123.8	73.8	12.7
$m_2n_1g_3$	115.1	70.1	11.8	119.7	69.0	11.1
$m_2n_2g_1$	100.4	63.5	11.8	101.5	67.0	11.1
$m_2n_2g_2$	99.4	64.0	12.8	102.7	65.2	12.0
$m_2n_2g_3$	98.9	52.0	11.2	102.7	56.5	10.6
$m_3n_1g_1$	96.1	62.3	10.9	101.2	69.0	10.3
$m_3n_1g_2$	93.2	57.4	11.6	102.8	61.9	10.1
$m_3n_1g_3$	96.5	56.7	10.8	100.9	55.0	10.2
$m_3n_2g_1$	91.1	58.2	10.2	103.5	62.0	9.6
$m_3n_2g_2$	92.4	57.5	11.2	105.1	59.0	10.1
$m_3n_2g_3$	93.9	52.3	10.1	105.7	47.0	9.5
$m_4n_1g_1$	108.6	72.6	12.0	118.0	71.0	11.3
$m_4n_1g_2$	108.0	67.6	12.7	118.5	66.5	12.0
$m_4n_1g_3$	107.8	65.2	12.1	119.5	63.0	11.4
$m_4n_2g_1$	102.6	60.0	11.2	106.3	61.7	10.6
$m_4n_2g_2$	101.2	59.2	12.1	101.5	64.2	11.1
$m_4n_2g_3$	102.8	51.0	11.8	102.7	54.0	11.2
$m_5n_1g_1$	105.6	72.5	11.5	109.3	73.0	11.2
$m_5n_1g_2$	107.1	68.1	12.3	108.7	65.8	11.6
$m_5n_1g_3$	106.0	52.0	11.7	109.9	57.0	11.0
$m_5n_2g_1$	100.3	66.3	10.9	94.9	64.0	10.3
$m_5n_2g_2$	99.0	58.2	12.0	102.1	61.2	10.3
$m_5n_2g_3$	100.1	57.6	11.4	96.7	58.5	10.2
SEm (±)	2.3	1.9	0.4	3.2	1.80	0.5
CD (0.05)	6.62	5.32	NS	9.53	5.22	NS

During the first year, bed method of planting at 30 cm x 30 cm spacing along with 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA ($m_2n_1g_2$) produced higher number of leaves per plant (118.3) and was on par with $m_2n_1g_1$ and $m_2n_1g_3$ (116.9 and 115.1 respectively) at 45 DAP. The treatment combination $m_2n_1g_1$ produced more number of leaves per plant (77.5) at 90 DAP and was on par with $m_4n_1g_1$ and $m_5n_1g_1$ (72.6 and 72.5). At 135 DAP, there was no significant variation in the number of leaves per plant.

In the second year, at 45 DAP, bed method of planting at 30 cm x 30 cm spacing along with 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA ($m_2n_1g_2$) produced higher number of leaves per plant (123.8) and was on par with $m_2n_1g_1$, $m_2n_1g_3$, $m_4n_1g_1$, $m_4n_1g_2$ and $m_4n_1g_3$. At 90 DAP, the significantly highest number of leaves (80.0) was observed in the treatment combination $m_2n_1g_1$ whereas at 135 DAP, no marked variation was observed in the number of leaves per plant.

4.1.1.6 Leaf Area

Tables 9a and 9b depict the variations in leaf area due to the individual and interaction effects of method of planting and nutrient management + growth promoter combination, during the two years.

There was significant variation in leaf area due to the methods of planting. At 45 DAP, the bed method of planting at 30 cm x 30 cm spacing (m_2) recorded higher leaf area (1328.12 cm^2) and was on par with the ridge method at 30 cm x 30 cm spacing (1314.84 cm^2) during the first year, whereas in the second year, it was significantly the highest in m_2 (1384.09 cm^2) at 45 DAP and at 90 DAP during both years (1017.12 and 1072.64 cm^2 respectively). Nevertheless, the variations were not marked at 135 DAP in the first year. In the second year, m_2 recorded the highest leaf area (71.00 cm^2) which was on par with ridge method at 30 cm x 30 cm spacing (m_4) at 135 DAP.

The sub plot effect was significant at all stages in both the years. In the first year, at 45 DAP, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1+

water spray (n_1g_3) recorded higher leaf area per plant (1328.58 cm^2) and was on par with n_1g_1 and n_1g_2. In the second year, it was maximum with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA (n_1g_2) at 45 DAP and on par with n_1g_1 and n_1g_3. At 90 DAP, the significantly highest leaf area per plant was observed due to the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) in both the years (1085.75 cm^2 and 1125.53 cm^2 respectively). At 135 DAP, during both the years, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA (n_1g_2) recorded higher leaf area (68.58 and 71.23 cm^2 respectively) and in the first year n_1g_2 remained on par with n_1g_1 alone.

With respect to the interaction effects, significant variations were seen in leaf area at 45 and 90 DAP in both the years. In the first year, at 45 DAP, bed method of planting with 30 cm x 30 cm spacing along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + water spray ($m_2n_1g_3$) effected higher leaf area per plant, but was on par with $m_2n_1g_1$, $m_2n_1g_2$, $m_4n_1g_1$, $m_4n_1g_2$ and $m_4n_1g_3$. In the second year at 45 DAP, $m_2n_1g_2$ recorded the highest leaf area (1512.26 cm^2) and was on par with $m_2n_1g_1$ and $m_2n_1g_3$ (1494.38 and 1475.31 cm^2). At 90 DAP, $m_2n_1g_1$ produced the significantly highest leaf area per plant (1166.68 cm^2) in the first year and second year (1247.71 cm^2).

4.1.2 Physiological and Biochemical Parameters

4.1.2.1 Dry Matter Production

The data on effect of methods of planting and combination of nutrient management + growth promoter on DMP at 45 days interval in the two years are given in Tables 10a and 10b.

There was significant variation in DMP at all stages in both the years with bed planting at 30 cm x 15 cm spacing (m_1) recording the significantly highest DMP at 45, 90 and 135 DAP in both the years (2.03, 4.55, 7.57 t ha^{-1} in the first year and 2.12, 5.11 and 8.37 t ha^{-1} in the second year respectively). Among the subplot treatments, the highest DMP at 45, 90 and 135 DAP were recorded with

Table 9a. Effect of method of planting and nutrient management x growth promoter on leaf area per plant, cm^2

Treatments	Leaf area					
	2019-20			2020-21		
	45 DAP	90 DAP	135 DAP	45 DAP	90 DAP	135 DAP
Method of planting						
m_1 - Bed method (30 cm x 15 cm)	1232.90	923.00	62.85	1233.47	969.96	60.52
m_2 - Bed method (30 cm x 30 cm)	1328.12	1017.12	68.56	1384.09	1072.64	71.00
m_3 - Ridge method (30 cm x 15 cm)	1221.32	883.22	60.97	1200.33	924.91	60.58
m_4 - Ridge method (30 cm x 30 cm)	1314.84	956.49	67.41	1360.87	1002.55	69.94
m_5 - Mound method (30 cm x 30 cm)	1225.98	947.24	66.44	1320.12	1006.12	66.78
SEm (±)	15.24	10.87	1.48	6.64	14.13	0.82
CD (0.05)	46.971	33.487	NS	20.465	43.540	2.54
Nutrient management x growth promoter						
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	1318.95	1085.75	66.70	1348.18	1125.53	66.04
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	1324.95	990.54	68.58	1356.11	1063.52	71.23
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1+ Water spray	1328.58	906.83	65.32	1346.15	970.84	65.56
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	1194.58	961.29	62.88	1255.94	1008.50	62.85
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	1211.08	922.49	65.19	1242.24	946.59	66.72
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	1209.66	805.57	62.81	1250.03	856.43	62.17
SEm (±)	16.11	10.46	1.13	8.03	11.83	0.96
CD (0.05)	45.392	29.462	3.191	22.614	33.317	2.70

Table 9b. Interaction effect of method of planting and combination of nutrient management + growth promoter on leaf area per plant, cm^2

Treatments	Leaf area					
	2019-20			2020-21		
	45 DAP	90 DAP	135 DAP	45 DAP	90 DAP	135 DAP
$m_1n_1g_1$	1256.78	1023.12	66.23	1288.96	1073.63	59.97
$m_1n_1g_2$	1286.37	952.74	63.51	1297.23	1038.59	63.40
$m_1n_1g_3$	1279.27	886.69	63.91	1278.69	923.42	59.79
$m_1n_2g_1$	1165.63	1000.72	60.40	1192.58	1048.26	58.41
$m_1n_2g_2$	1186.94	882.95	61.55	1173.28	884.06	62.84
$m_1n_2g_3$	1222.45	791.78	61.51	1170.05	851.79	58.72
$m_2n_1g_1$	1449.73	1166.68	66.27	1494.38	1247.71	68.47
$m_2n_1g_2$	1432.50	1084.69	76.78	1512.26	1168.14	80.60
$m_2n_1g_3$	1454.67	1030.90	66.45	1475.31	1128.60	68.25
$m_2n_2g_1$	1201.14	1001.01	66.63	1287.19	1022.49	68.84
$m_2n_2g_2$	1215.35	975.01	71.89	1267.89	1030.47	75.15
$m_2n_2g_3$	1215.35	844.39	63.34	1267.51	838.46	64.67
$m_3n_1g_1$	1197.47	1041.65	63.87	1231.66	1004.42	62.66
$m_3n_1g_2$	1216.53	925.09	61.86	1194.60	924.37	62.47
$m_3n_1g_3$	1194.04	822.42	61.07	1236.14	913.55	61.98
$m_3n_2g_1$	1225.29	926.29	60.16	1168.14	937.73	58.17
$m_3n_2g_2$	1243.76	881.45	60.11	1184.69	926.89	61.37
$m_3n_2g_3$	1250.86	702.41	58.75	1186.76	842.48	56.81
$m_4n_1g_1$	1397.29	1103.52	67.83	1372.76	1133.76	70.08
$m_4n_1g_2$	1402.97	1006.34	71.47	1404.26	1089.42	76.02
$m_4n_1g_3$	1414.33	941.98	68.42	1381.73	1050.94	70.28
$m_4n_2g_1$	1257.96	921.36	63.34	1346.60	966.19	65.44
$m_4n_2g_2$	1201.14	958.72	66.63	1316.31	954.20	69.65
$m_4n_2g_3$	1215.35	807.03	66.75	1343.54	820.80	68.15
$m_5n_1g_1$	1293.47	1093.78	69.31	1353.12	1168.11	69.03
$m_5n_1g_2$	1286.37	983.83	69.26	1372.20	1097.10	73.66
$m_5n_1g_3$	1300.57	852.16	66.73	1358.89	837.67	67.51
$m_5n_2g_1$	1122.90	957.08	63.87	1285.17	1067.84	63.40
$m_5n_2g_2$	1208.24	914.33	65.78	1269.04	937.35	64.59
$m_5n_2g_3$	1144.32	882.23	63.69	1282.30	928.64	62.47
SEm (±)	36.25	23.95	2.74	17.68	27.97	2.13
CD (0.05)	101.500	65.878	NS	50.566	74.50	NS

Table 10a. Effect of method of planting and nutrient management x growth promoter on dry matter production, t ha^{-1}

Treatments	Dry Matter Production					
	2019-20			2020-21		
	45 DAP	90 DAP	135 DAP	45 DAP	90 DAP	135 DAP
Method of planting						
m_1 - Bed method (30 cm x 15 cm)	2.03	4.55	7.57	2.12	5.11	8.37
m_2 - Bed method (30 cm x 30 cm)	1.21	3.05	5.19	1.27	3.40	5.68
m_3 - Ridge method (30 cm x 15 cm)	1.89	4.32	7.37	1.97	4.81	8.06
m_4 - Ridge method (30 cm x 30 cm)	1.15	2.91	4.90	1.21	3.24	5.36
m_5 - Mound method (30 cm x 30 cm)	1.04	2.57	4.29	1.09	2.86	4.70
SEm (±)	0.01	0.02	0.04	0.01	0.02	0.03
CD (0.05)	0.044	0.060	0.123	0.026	0.058	0.104
Nutrient management x growth promoter						
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	1.52	3.83	6.53	1.59	4.27	7.15
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	1.50	3.58	6.08	1.57	4.04	6.73
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1+ Water spray	1.49	3.49	5.89	1.57	3.89	6.47
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	1.44	3.43	5.75	1.51	3.82	6.29
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	1.42	3.33	5.56	1.48	3.71	6.09
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	1.42	3.22	5.37	1.49	3.59	5.87
SEm (±)	0.01	0.02	0.04	0.02	0.02	0.04
CD (0.05)	0.038	0.058	0.123	0.043	0.068	0.109

Table 10b. Interaction effect of method of planting and combination of nutrient management + growth promoter on dry matter production, t ha^{-1}

Treatments	Dry Matter Production					
	2019-20			2020-21		
	45 DAP	90 DAP	135 DAP	45 DAP	90 DAP	135 DAP
$m_1n_1g_1$	2.12	4.95	8.27	2.22	5.51	9.05
$m_1n_1g_2$	2.08	4.60	7.67	2.18	5.37	8.78
$m_1n_1g_3$	2.03	4.49	7.57	2.13	5.00	8.42
$m_1n_2g_1$	1.96	4.55	7.61	2.05	5.07	8.32
$m_1n_2g_2$	2.00	4.40	7.26	2.09	4.91	7.94
$m_1n_2g_3$	1.97	4.33	7.03	2.06	4.82	7.70
$m_2n_1g_1$	1.23	3.51	6.19	1.29	3.91	6.77
$m_2n_1g_2$	1.25	3.21	5.42	1.30	3.58	5.94
$m_2n_1g_3$	1.19	3.12	5.27	1.27	3.48	5.77
$m_2n_2g_1$	1.22	2.91	4.94	1.28	3.24	5.40
$m_2n_2g_2$	1.16	2.82	4.76	1.21	3.14	5.21
$m_2n_2g_3$	1.22	2.75	4.56	1.28	3.06	4.99
$m_3n_1g_1$	2.01	4.67	7.83	2.10	5.21	8.57
$m_3n_1g_2$	1.92	4.41	7.52	2.01	4.91	8.23
$m_3n_1g_3$	1.95	4.30	7.34	2.04	4.79	8.04
$m_3n_2g_1$	1.87	4.31	7.38	1.96	4.80	8.08
$m_3n_2g_2$	1.78	4.17	7.13	1.81	4.65	7.80
$m_3n_2g_3$	1.83	4.07	6.99	1.89	4.53	7.65
$m_4n_1g_1$	1.13	3.20	5.53	1.18	3.56	6.05
$m_4n_1g_2$	1.21	3.07	5.17	1.27	3.42	5.66
$m_4n_1g_3$	1.20	2.95	4.95	1.25	3.28	5.41
$m_4n_2g_1$	1.12	2.84	4.72	1.18	3.16	5.16
$m_4n_2g_2$	1.16	2.81	4.65	1.21	3.13	5.09
$m_4n_2g_3$	1.10	2.60	4.36	1.15	2.90	4.77
$m_5n_1g_1$	1.11	2.82	4.86	1.16	3.14	5.32
$m_5n_1g_2$	1.04	2.64	4.59	1.09	2.94	5.02
$m_5n_1g_3$	1.10	2.62	4.32	1.15	2.92	4.72
$m_5n_2g_1$	1.03	2.53	4.11	1.07	2.82	4.50
$m_5n_2g_2$	1.00	2.43	4.00	1.04	2.71	4.38
$m_5n_2g_3$	1.00	2.37	3.89	1.05	2.64	4.25
SEm (±)	0.03	0.05	0.10	0.03	0.05	0.09
CD (0.05)	0.085	0.130	0.276	0.097	0.153	0.243

application of humic acid along with 60:30:120 kg NPK ha^{-1} and PGPR Mix 1 (n_1g_1) and it was on par with n_1g_2 and n_1g_3 at 45 DAP (1.52, 1.50 and 1.49 t ha^{-1} in the first year) and 1.59, 1.57 and 1.57 t ha^{-1} in the second year respectively.

Perusal of data in Table 10b revealed that the interactions were also significant at all the stages in both the years. At 45 DAP, the treatment combination $m_1n_1g_1$ produced the maximum dry matter in both years, 2.12 t ha^{-1} in the first year and 2.22 t ha^{-1} in the second year. In the first year $m_1n_1g_1$ was on par with $m_1n_1g_2$ (2.08 t ha^{-1}) and in the second year, it was on par with $m_1n_1g_2$ and $m_1n_1g_3$ (2.18 and 2.13 t ha^{-1} respectively). The superiority of $m_1n_1g_1$ was evident in both the years at 90 and 135 DAP, although in the second year it was on par with $m_1n_1g_2$ at 90 DAP.

4.1.2.2 Crop Growth Rate

Tables 11a and 11b revealed the main and interaction effects of methods of planting and combination of nutrient management and growth promoter on CGR at 45 days interval.

Crop growth rate varied significantly due to methods of planting and combination of nutrient management and growth promoter. Bed method of planting with 30 cm x 15 cm spacing (m_1) brought about the significantly highest CGR up to 45 DAP and between 45 and 90 DAP during both the years (4.50 and 5.61 g m^{-2} day^{-1} during first year and 4.71 and 6.65 g cm^{-2} day^{-1} during second year respectively). The lowest CGR values were observed in m_5 (mound method at wider spacing). Between 90 and 135 DAP, higher CGR was recorded in ridge and bed method of planting at closer spacing and comparable in the first and second year. The values were 6.77 and 6.70 g m^{-2} day^{-1} in the first year and 7.21 and 7.24 g m^{-2} day^{-1} in the second year respectively.

Application of nutrients and growth promoters influenced CGR in all the growth stages in both the years. In the early stages, CGR was higher in the NPK combination with PGPR and humic acid (n_1g_1), on par with n_1g_2 and n_1g_3. The trend remained similar between 45-90 and 90-135 DAP.

The interactions could induce significant variations in CGR only between 45-90 DAP and 90-135 DAP during both the years. In both years, the highest CGR were observed in $m_1n_1g_1$. In the first year, the maximum CGR in $m_1n_1g_1$ (6.29 g m^{-2} day^{-1}) was on par with $m_3n_1g_1$ (5.93 g m^{-2} day^{-1}). During the second year, the CGR realized in $m_1n_1g_1$ (7.32 g m^{-2} day^{-1}) remained comparable with $m_1n_1g_2$ (7.10 g m^{-2} day^{-1}). Between 90-135 DAP, the CGR produced by $m_1n_1g_1$ was 7.39 g m^{-2} day^{-1} in the first year and 7.87 g m^{-2} day^{-1} in the second year, the latter was on par with $m_1n_1g_2$ and $m_1n_1g_3$ (7.58 and 7.61 g m^{-2} day^{-1}).

4.1.2.3 Relative Growth Rate

The RGR computed between 45-90 and 90-135 DAP in both the years are presented in Tables 12a and 12b.

Perusal of the data indicated that RGR between 45-90 DAP was higher in ridge method of planting at 30 cm x 30 cm spacing (m_4) and on par with m_2 and m_5 in both the years (20.52, 20.41 and 19.97 x 10^{-3} g g^{-1} day^{-1} in the first year and 21.92, 21.81 and 21.36 x 10^{-3} g g^{-1} day^{-1} in the second year respectively). There was no marked variation in RGR due to methods of planting between 90-135 DAP during both the years.

Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) resulted in the significantly highest value of RGR during 45-90 DAP in both the years (20.95 and 22.35 x 10^{-3} g g^{-1} day^{-1}in the first and second year respectively). Between 90-135 DAP, the significantly highest RGR assessed in n_1g_1 (11.95 x 10^{-3} g g^{-1} day^{-1}) was on par with n_1g_2 in the first year, and during second year, the highest RGR in n_1g_1 (11.55 x 10^{-3} g g^{-1} day^{-1}) was on par with n_1g_2 and n_1g_3. The interaction effect of methods of planting and combination of nutrient management and growth promoter failed to raise the variations to the level of significance in both years.

Table 11a. Effect of method of planting and nutrient management x growth promoter on crop growth rate, g m^{-2} day^{-1}

Treatments	Crop Growth Rate					
	2019-20			2020-21		
	Up to 45 DAP	45-90 DAP	90-135 DAP	Up to 45 DAP	45-90 DAP	90-135 DAP
Method of planting						
m_1 - Bed method (30 cm x 15 cm)	4.50	5.61	6.70	4.71	6.65	7.24
m_2 - Bed method (30 cm x 30 cm)	2.70	4.09	4.75	2.82	4.74	5.06
m_3 - Ridge method (30 cm x 15 cm)	4.20	5.40	6.77	4.40	6.30	7.21
m_4 - Ridge method (30 cm x 30 cm)	2.56	3.90	4.42	2.68	4.52	4.70
m_5 - Mound method (30 cm x 30 cm)	2.32	3.39	3.83	2.43	3.93	4.08
SEm (±)	0.05	0.06	0.06	0.05	0.04	0.06
CD (0.05)	0.142	0.184	0.172	0.142	0.113	0.174
Nutrient management x growth promoter						
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	3.38	5.13	6.01	3.53	5.95	6.41
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	3.33	4.64	5.53	3.49	5.50	5.96
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	3.33	4.44	5.32	3.48	5.17	5.73
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	3.20	4.42	5.16	3.35	5.14	5.49
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	3.15	4.24	4.97	3.30	4.94	5.29
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	3.17	3.99	4.77	3.31	4.66	5.07
SEm (±)	0.04	0.06	0.06	0.04	0.06	0.08
CD (0.05)	0.106	0.177	0.182	0.121	0.172	0.218

Table 11b. Interaction effect of method of planting and combination of nutrient management + growth promoter on crop growth rate, g m^{-2} day^{-1}

Treatments	Crop Growth Rate					
	2019-20			2020-21		
	Up to 45 DAP	45-90 DAP	90-135 DAP	Up to 45 DAP	45-90 DAP	90-135 DAP
$m_1n_1g_1$	4.71	6.29	7.39	4.92	7.32	7.87
$m_1n_1g_2$	4.62	5.59	6.82	4.83	7.10	7.58
$m_1n_1g_3$	4.52	5.46	6.84	4.73	6.39	7.61
$m_1n_2g_1$	4.36	5.75	6.79	4.56	6.71	7.23
$m_1n_2g_2$	4.45	5.34	6.34	4.65	6.25	6.75
$m_1n_2g_3$	4.38	5.24	6.01	4.59	6.13	6.38
$m_2n_1g_1$	2.73	5.06	5.95	2.86	5.82	6.36
$m_2n_1g_2$	2.77	4.37	4.92	2.90	5.06	5.24
$m_2n_1g_3$	2.69	4.25	4.77	2.81	4.92	5.08
$m_2n_2g_1$	2.72	3.75	4.50	2.84	4.37	4.80
$m_2n_2g_2$	2.57	3.70	4.31	2.69	4.29	4.60
$m_2n_2g_3$	2.71	3.39	4.03	2.84	3.96	4.29
$m_3n_1g_1$	4.46	5.93	7.01	4.67	6.91	7.46
$m_3n_1g_2$	4.26	5.54	6.92	4.46	6.46	7.38
$m_3n_1g_3$	4.33	5.21	6.77	4.53	6.11	7.22
$m_3n_2g_1$	4.16	5.42	6.82	4.35	6.33	7.27
$m_3n_2g_2$	3.96	5.31	6.58	4.14	6.18	7.02
$m_3n_2g_3$	4.06	4.98	6.49	4.25	5.82	6.92
$m_4n_1g_1$	2.51	4.59	5.19	2.63	5.29	5.53
$m_4n_1g_2$	2.69	4.12	4.68	2.82	4.78	4.99
$m_4n_1g_3$	2.66	3.89	4.45	2.78	4.51	4.73
$m_4n_2g_1$	2.50	3.81	4.18	2.61	4.41	4.45
$m_4n_2g_2$	2.58	3.66	4.09	2.70	4.26	4.36
$m_4n_2g_3$	2.44	3.33	3.91	2.56	3.88	4.16
$m_5n_1g_1$	2.47	3.80	4.53	2.58	4.41	4.83
$m_5n_1g_2$	2.31	3.56	4.32	2.41	4.12	4.61
$m_5n_1g_3$	2.44	3.39	3.77	2.55	3.94	4.01
$m_5n_2g_1$	2.28	3.35	3.50	2.39	3.89	3.72
$m_5n_2g_2$	2.21	3.18	3.49	2.32	3.70	3.72
$m_5n_2g_3$	2.23	3.03	3.38	2.33	3.53	3.59
SEm (±)	0.09	0.14	0.14	0.10	0.13	0.17
CD (0.05)	NS	0.395	0.408	NS	0.385	0.488

Table 12a. Effect of method of planting and nutrient management x growth promoter on relative growth rate, g $g^{-1}day^{-1}$

Treatments	Relative Growth Rate ($x10^{-3}$)			
	2019-20		2020-21	
	45-90 DAP	90-135 DAP	45-90 DAP	90-135 DAP
Method of planting				
m_1 - Bed method (30 cm x 15 cm)	17.97	11.29	19.54	10.94
m_2 - Bed method (30 cm x 30 cm)	20.41	11.75	21.81	11.35
m_3 - Ridge method (30 cm x 15 cm)	18.34	11.86	19.74	11.46
m_4 - Ridge method (30 cm x 30 cm)	20.52	11.55	21.92	11.15
m_5 - Mound method (30 cm x 30 cm)	19.97	11.39	21.36	10.98
SEm (±)	0.19	0.13	0.25	0.11
CD (0.05)	0.589	NS	0.776	NS
Nutrient management x growth promoter				
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	20.95	11.95	22.35	11.55
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	19.71	11.76	21.31	11.35
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1+ Water spray	19.13	11.55	20.53	11.22
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	19.45	11.43	20.85	11.03
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	19.13	11.39	20.53	10.99
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	18.29	11.32	19.69	10.92
SEm (±)	0.30	0.13	0.28	0.15
CD (0.05)	0.839	0.372	0.785	0.428

Table 12b. Interaction effect of method of planting and combination of nutrient management + growth promoter on relative growth rate, g $g^{-1}day^{-1}$

Treatments	Relative Growth Rate ($x10^{-3}$)			
	2019-20		2020-21	
	45-90 DAP	90-135 DAP	45-90 DAP	90-135 DAP
$m_1n_1g_1$	18.85	11.43	20.25	11.03
$m_1n_1g_2$	17.63	11.37	20.07	10.93
$m_1n_1g_3$	17.61	11.60	19.01	11.59
$m_1n_2g_1$	18.71	11.42	20.11	11.02
$m_1n_2g_2$	17.53	11.10	18.93	10.70
$m_1n_2g_3$	17.47	10.78	18.86	10.38
$m_2n_1g_1$	23.28	12.61	24.67	12.20
$m_2n_1g_2$	21.05	11.65	22.45	11.24
$m_2n_1g_3$	21.07	11.62	22.47	11.21
$m_2n_2g_1$	19.29	11.74	20.69	11.33
$m_2n_2g_2$	19.78	11.64	21.18	11.23
$m_2n_2g_3$	18.01	11.27	19.41	10.87
$m_3n_1g_1$	18.78	11.46	20.18	11.06
$m_3n_1g_2$	18.50	11.88	19.90	11.48
$m_3n_1g_3$	17.56	11.92	18.96	11.51
$m_3n_2g_1$	18.55	11.95	19.95	11.54
$m_3n_2g_2$	18.89	11.93	20.29	11.52
$m_3n_2g_3$	17.78	12.03	19.18	11.63
$m_4n_1g_1$	23.11	12.18	24.50	11.78
$m_4n_1g_2$	20.63	11.62	22.02	11.21
$m_4n_1g_3$	20.03	11.52	21.43	11.12
$m_4n_2g_1$	20.59	11.30	21.99	10.90
$m_4n_2g_2$	19.64	11.21	21.04	10.81
$m_4n_2g_3$	19.11	11.49	20.51	11.08
$m_5n_1g_1$	20.74	12.08	22.14	11.67
$m_5n_1g_2$	20.73	12.27	22.13	11.87
$m_5n_1g_3$	19.37	11.10	20.77	10.70
$m_5n_2g_1$	20.09	10.74	21.49	10.34
$m_5n_2g_2$	19.80	11.10	21.20	10.69
$m_5n_2g_3$	19.06	11.03	20.46	10.63
SEm (±)	0.64	0.30	0.62	0.33
CD (0.05)	NS	NS	NS	NS

4.1.2.4 Leaf Area Index

The significant influence of the treatments and the combinations on LAI are depicted in Tables 13a and 13b. During both the years, LAI was significantly the highest in m_1 closely followed by m_3 at 45, 90 and 135 DAP.

Analysing the combination effects, irrespective of the growth promoter included, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 recorded higher LAI during both the years at 45 DAP. At 90 DAP in both the years, the significantly highest LAI (1.67 and 1.71 respectively) were accounted in the application of NPK + PGPR Mix 1 + humic acid (n_1g_1). At 135 DAP, LAI was maximum in the combination with BA (n_1g_2) in both years and on par with n_1g_1, n_1g_3 and n_2g_2 in the first year but, significantly superior in the second year.

The interaction effect of the treatments did not exert any significant effect on LAI at 45 DAP in the first year. However, during the second year, the inclusion of PGPR and growth promoters in the bed method at 30 cm x 15 cm resulted in significant variations in LAI. At 90 DAP, $m_3n_1g_1$ recorded higher LAI and was on par with $m_1n_1g_1$ and $m_1n_2g_1$ during the first year and the treatment combinations $m_1n_1g_1$, $m_1n_1g_2$ and $m_1n_2g_1$ were on par in the second year. There was no significant variation in LAI due to treatments at 135 DAP in both years.

4.1.2.5 Net Assimilation Rate

The variations in NAR of Chinese potato due to the effect of the method of planting and the nutrient management + growth promoter combination between 45-90 and 90-135 DAP are presented in Tables 14a and 14b. Net assimilation rate was the highest in bed method of planting at 30 cm x 30 cm spacing (m_2) at all stages and was on par with that realised in the ridge method planting at 30 cm x 30 cm (m_4) in both the years. Combination of nutrient management and growth promoter also exerted significant influence on NAR in both the years. The significantly highest NAR was recorded in the interaction, 60:30:120 kg NPK ha^{-1} x PGPR Mix 1 + humic acid (n_1g_1) during 45-90 DAP in both the years. During

90-135 DAP, NAR in the treatments n_1g_1, n_1g_3 and n_2g_3 were comparable in the first year and n_1g_1 and n_1g_3 were on par in the second year.

The interaction effects on NAR between 45-90 DAP were found to be non significant in the two years. Nevertheless, NAR between 90-135 DAP was significantly the highest in $m_2n_1g_1$ during the both the years (13.96 and 14.08 x 10^{-4} g cm^{-2} day^{-1}).

4.1.2.6 Chlorophyll Content

The variation in chlorophyll content of leaves at 45 days interval due to the effect of methods of planting and combination of nutrient management and growth promoter are given in Tables 15a and 15b. A marked influence was observed at 45 DAP in the first year, with the chlorophyll content estimated at 45 DAP being significantly the highest in plants grown on beds at 30 cm x 30 cm spacing (m_2) in the first and second year. In the confirmation experiment it was on par with m_4.

At 90 DAP, there was no significant variation in chlorophyll content due to methods of planting in the first year. The treatment m_2 recorded higher chlorophyll content (0.642 mg g^{-1}) in the second year and was on par with that (0.628 mg g^{-1}) in the ridge method of planting at 30 cm x 30 cm spacing. At 135 DAP, there was no significant variation in chlorophyll content in the both the years.

The nutrient management + growth promoter combination exerted significant influence on chlorophyll content at 45 and 90 DAP in both years with the inclusion of PGPR in the treatments resulting in superior contents. At 45 DAP, higher chlorophyll (0.604 mg g^{-1}) was recorded in n_1g_3 and was on par with n_1g_1 and n_1g_2 in the first year. During the second year, n_1g_2 resulted in the highest chlorophyll content (0.590 mg g^{-1}). At 90 DAP it was maximum in n_1g_1 during both the years (0.689 and 0.671 mg g^{-1} respectively).

Table 13a. Effect of method of planting and nutrient management x growth promoter on leaf area index

Treatments	Leaf Area Index					
	2019-20			2020-21		
	45 DAP	90 DAP	135 DAP	45 DAP	90 DAP	135 DAP
Method of planting						
m_1 - Bed method (30 cm x 15 cm)	2.74	2.05	0.140	2.74	2.16	0.134
m_2 - Bed method (30 cm x 30 cm)	1.48	1.10	0.076	1.54	1.19	0.079
m_3 - Ridge method (30 cm x 15 cm)	2.71	1.96	0.135	2.67	2.06	0.135
m_4 - Ridge method (30 cm x 30 cm)	1.46	1.06	0.075	1.51	1.11	0.078
m_5 - Mound method (30 cm x 30 cm)	1.36	1.05	0.074	1.47	1.12	0.074
SEm (±)	0.03	0.02	0.003	0.01	0.03	0.001
CD (0.05)	0.079	0.059	0.0082	0.034	0.083	0.0031
Nutrient management x growth promoter						
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	2.01	1.67	0.103	2.06	1.71	0.101
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	2.03	1.52	0.104	2.06	1.62	0.107
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	2.03	1.39	0.100	2.05	1.49	0.100
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	1.86	1.50	0.097	1.92	1.56	0.096
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	1.89	1.42	0.099	1.90	1.45	0.102
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	1.89	1.23	0.097	1.91	1.33	0.095
SEm (±)	0.03	0.02	0.002	0.01	0.02	0.001
CD (0.05)	0.078	0.050	0.0054	0.034	0.055	0.0041

Table 13b. Interaction effect of method of planting and combination of nutrient management + growth promoter on leaf area index

Treatments	Leaf Area Index					
	2019-20			2020-21		
	45 DAP	90 DAP	135 DAP	45 DAP	90 DAP	135 DAP
$m_1n_1g_1$	2.79	2.27	0.147	2.86	2.39	0.133
$m_1n_1g_2$	2.86	2.12	0.141	2.88	2.31	0.141
$m_1n_1g_3$	2.84	1.97	0.142	2.84	2.05	0.133
$m_1n_2g_1$	2.59	2.22	0.134	2.65	2.33	0.130
$m_1n_2g_2$	2.64	1.96	0.137	2.61	1.96	0.140
$m_1n_2g_3$	2.72	1.76	0.137	2.60	1.89	0.130
$m_2n_1g_1$	1.61	1.30	0.074	1.66	1.39	0.076
$m_2n_1g_2$	1.59	1.21	0.085	1.68	1.30	0.090
$m_2n_1g_3$	1.62	1.15	0.074	1.64	1.25	0.076
$m_2n_2g_1$	1.33	1.11	0.074	1.43	1.14	0.076
$m_2n_2g_2$	1.35	1.08	0.080	1.41	1.14	0.084
$m_2n_2g_3$	1.35	0.94	0.070	1.41	0.93	0.072
$m_3n_1g_1$	2.66	2.31	0.142	2.74	2.23	0.139
$m_3n_1g_2$	2.70	2.06	0.137	2.65	2.05	0.139
$m_3n_1g_3$	2.65	1.83	0.136	2.75	2.03	0.138
$m_3n_2g_1$	2.72	2.06	0.134	2.60	2.08	0.129
$m_3n_2g_2$	2.76	1.96	0.134	2.63	2.06	0.136
$m_3n_2g_3$	2.78	1.56	0.131	2.64	1.87	0.126
$m_4n_1g_1$	1.55	1.23	0.075	1.53	1.26	0.078
$m_4n_1g_2$	1.56	1.12	0.079	1.56	1.21	0.084
$m_4n_1g_3$	1.57	1.05	0.076	1.54	1.17	0.078
$m_4n_2g_1$	1.40	1.02	0.070	1.50	1.07	0.073
$m_4n_2g_2$	1.33	1.07	0.074	1.46	1.06	0.077
$m_4n_2g_3$	1.35	0.90	0.074	1.49	0.91	0.076
$m_5n_1g_1$	1.44	1.22	0.077	1.50	1.30	0.077
$m_5n_1g_2$	1.43	1.09	0.077	1.52	1.22	0.082
$m_5n_1g_3$	1.45	0.95	0.074	1.51	0.93	0.075
$m_5n_2g_1$	1.25	1.06	0.071	1.43	1.19	0.070
$m_5n_2g_2$	1.34	1.02	0.073	1.41	1.04	0.072
$m_5n_2g_3$	1.27	0.98	0.071	1.42	1.03	0.069
SEm (±)	0.062	0.04	0.005	0.03	0.05	0.003
CD (0.05)	NS	0.111	NS	0.075	0.124	NS

Table 14a. Effect of method of planting and nutrient management x growth promoter on net assimilation rate, g cm^{-2} day $^{-1}$

Treatments	Net Assimilation Rate (x10^{-4})			
	2019-20		2020-21	
	45-90 DAP	90-135 DAP	45-90 DAP	90-135 DAP
Method of planting				
m_1 - Bed method (30 cm x 15 cm)	2.36	9.42	2.73	9.94
m_2 - Bed method (30 cm x 30 cm)	3.15	12.13	3.48	12.35
m_3 - Ridge method (30 cm x 15 cm)	2.33	9.97	2.68	10.25
m_4 - Ridge method (30 cm x 30 cm)	3.11	11.85	3.47	12.09
m_5 - Mound method (30 cm x 30 cm)	2.82	10.39	3.06	10.61
SEm (±)	0.03	0.13	0.03	0.14
CD (0.05)	0.089	0.415	0.086	0.439
Nutrient management x growth promoter				
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	2.91	11.20	3.28	11.65
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	2.74	10.79	3.08	10.90
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	2.73	11.09	3.06	11.35
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	2.77	10.37	3.06	10.68
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	2.69	10.18	3.04	10.57
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	2.69	10.88	3.00	11.13
SEm (±)	0.03	0.14	0.04	0.15
CD (0.05)	0.090	0.386	0.120	0.428

Table 14b. Interaction effect of method of planting and combination of nutrient management + growth promoter on net assimilation rate, g cm^{-2} day $^{-1}$

Treatments	Net Assimilation Rate (x10^{-4})			
	2019-20		2020-21	
	45-90 DAP	90-135 DAP	45-90 DAP	90-135 DAP
$m_1n_1g_1$	2.49	9.52	2.80	10.08
$m_1n_1g_2$	2.26	9.35	2.75	9.78
$m_1n_1g_3$	2.29	9.83	2.63	10.85
$m_1n_2g_1$	2.40	9.12	2.70	9.49
$m_1n_2g_2$	2.34	9.26	2.75	9.77
$m_1n_2g_3$	2.38	9.46	2.75	9.69
$m_2n_1g_1$	3.49	13.96	3.83	14.08
$m_2n_1g_2$	3.14	11.63	3.41	11.59
$m_2n_1g_3$	3.11	12.20	3.42	12.09
$m_2n_2g_1$	3.08	11.75	3.42	12.21
$m_2n_2g_2$	3.05	11.21	3.37	11.34
$m_2n_2g_3$	2.99	12.04	3.43	12.79
$m_3n_1g_1$	2.39	9.01	2.79	9.90
$m_3n_1g_2$	2.34	9.76	2.76	10.38
$m_3n_1g_3$	2.35	10.41	2.58	10.27
$m_3n_2g_1$	2.28	9.69	2.71	10.34
$m_3n_2g_2$	2.27	9.68	2.65	9.91
$m_3n_2g_3$	2.36	11.26	2.61	10.70
$m_4n_1g_1$	3.32	12.57	3.81	13.03
$m_4n_1g_2$	3.11	11.92	3.47	11.79
$m_4n_1g_3$	3.01	12.01	3.36	11.75
$m_4n_2g_1$	3.17	11.74	3.47	11.97
$m_4n_2g_2$	3.07	11.01	3.40	11.60
$m_4n_2g_3$	3.01	11.85	3.29	12.39
$m_5n_1g_1$	2.88	10.97	3.15	11.18
$m_5n_1g_2$	2.84	11.29	3.02	10.96
$m_5n_1g_3$	2.87	11.01	3.29	11.80
$m_5n_2g_1$	2.91	9.55	2.98	9.40
$m_5n_2g_2$	2.72	9.75	3.04	10.25
$m_5n_2g_3$	2.71	9.77	2.90	10.08
SEm (±)	0.07	0.31	0.09	0.34
CD (0.05)	NS	0.864	NS	0.957

Table 15a. Effect of method of planting and nutrient management x growth promoter on chlorophyll content, mg g^{-1}

Treatments	Chlorophyll content					
	2019-20			2020-21		
	45 DAP	90 DAP	135 DAP	45 DAP	90 DAP	135 DAP
Method of planting						
m_1 - Bed method (30 cm x 15 cm)	0.534	0.636	0.348	0.551	0.582	0.350
m_2 - Bed method (30 cm x 30 cm)	0.607	0.654	0.353	0.590	0.642	0.379
m_3 - Ridge method (30 cm x 15 cm)	0.524	0.640	0.346	0.541	0.580	0.347
m_4 - Ridge method (30 cm x 30 cm)	0.576	0.611	0.346	0.585	0.628	0.379
m_5 - Mound method (30 cm x 30 cm)	0.557	0.621	0.346	0.546	0.612	0.367
SEm (±)	0.007	0.011	0.006	0.008	0.006	0.011
CD (0.05)	0.0203	NS	NS	0.0259	0.0193	NS
Nutrient management x growth promoter						
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	0.603	0.689	0.363	0.588	0.671	0.374
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	0.586	0.656	0.345	0.590	0.638	0.368
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	0.604	0.631	0.350	0.588	0.613	0.362
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	0.540	0.625	0.345	0.532	0.598	0.361
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	0.525	0.608	0.348	0.539	0.582	0.359
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	0.498	0.586	0.336	0.538	0.552	0.361
SEm (±)	0.007	0.009	0.007	0.007	0.007	0.010
CD (0.05)	0.0199	0.0250	NS	0.0189	0.0210	NS

Table 15b. Interaction effect of method of planting and combination of nutrient management + growth promoter on chlorophyll content, mg g^{-1}

Treatments	Chlorophyll content					
	2019-20			2020-21		
	45 DAP	90 DAP	135 DAP	45 DAP	90 DAP	135 DAP
$m_1n_1g_1$	0.568	0.702	0.365	0.573	0.641	0.350
$m_1n_1g_2$	0.568	0.678	0.335	0.575	0.629	0.346
$m_1n_1g_3$	0.590	0.628	0.358	0.569	0.587	0.351
$m_1n_2g_1$	0.517	0.620	0.358	0.519	0.573	0.345
$m_1n_2g_2$	0.504	0.598	0.346	0.528	0.559	0.355
$m_1n_2g_3$	0.455	0.593	0.329	0.544	0.504	0.351
$m_2n_1g_1$	0.666	0.712	0.380	0.639	0.738	0.395
$m_2n_1g_2$	0.660	0.671	0.358	0.650	0.673	0.377
$m_2n_1g_3$	0.696	0.651	0.346	0.631	0.647	0.371
$m_2n_2g_1$	0.566	0.630	0.355	0.535	0.627	0.372
$m_2n_2g_2$	0.550	0.639	0.336	0.542	0.609	0.379
$m_2n_2g_3$	0.504	0.622	0.343	0.541	0.559	0.378
$m_3n_1g_1$	0.554	0.666	0.363	0.531	0.614	0.366
$m_3n_1g_2$	0.546	0.650	0.355	0.528	0.605	0.359
$m_3n_1g_3$	0.530	0.642	0.334	0.531	0.587	0.339
$m_3n_2g_1$	0.517	0.645	0.325	0.545	0.573	0.344
$m_3n_2g_2$	0.502	0.624	0.352	0.554	0.556	0.334
$m_3n_2g_3$	0.494	0.611	0.344	0.557	0.547	0.340
$m_4n_1g_1$	0.620	0.680	0.361	0.622	0.690	0.385
$m_4n_1g_2$	0.589	0.651	0.334	0.625	0.653	0.381
$m_4n_1g_3$	0.625	0.606	0.368	0.630	0.632	0.383
$m_4n_2g_1$	0.556	0.599	0.328	0.560	0.616	0.378
$m_4n_2g_2$	0.541	0.575	0.360	0.535	0.599	0.372
$m_4n_2g_3$	0.523	0.556	0.327	0.541	0.579	0.373
$m_5n_1g_1$	0.606	0.686	0.347	0.576	0.671	0.373
$m_5n_1g_2$	0.569	0.631	0.345	0.573	0.630	0.376
$m_5n_1g_3$	0.578	0.627	0.346	0.579	0.610	0.367
$m_5n_2g_1$	0.544	0.630	0.357	0.500	0.603	0.366
$m_5n_2g_2$	0.529	0.602	0.346	0.538	0.586	0.356
$m_5n_2g_3$	0.516	0.548	0.337	0.509	0.572	0.365
SEm (±)	0.016	0.021	0.016	0.016	0.016	0.023
CD (0.05)	0.0445	NS	NS	0.0423	NS	NS

The interaction could cause significant variations at 45 DAP alone in both the years. As observed in the main and sub plot effects, treatments including PGPR with the bed method of planting recorded the highest chlorophyll content. In the first year, bed method of planting at 30 cm x 30 cm spacing along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + water spray ($m_2n_1g_3$) recorded higher chlorophyll content (0.696 mg g^{-1}) and was on par with $m_2n_1g_1$ and $m_2n_1g_2$ (0.666 and 0.660 mg g^{-1} respectively). In the second year, higher content of chlorophyll was assessed in the treatment combination $m_2n_1g_2$, but was on par with $m_2n_1g_1$, $m_2n_1g_3$, $m_4n_1g_1$, $m_4n_1g_2$ and $m_4n_1g_3$.

4.1.2.7 Days to Senescence

The influence of the treatments individually and in combination on the number of days taken to initiation of senescence is presented in Tables 16a and 16b. There was significant variation in days taken to senescence due to the combination of nutrient management and growth promoter alone (Tables 16a and 16b). In the first year, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA (n_1g_2) could significantly extend the time for senescence (118.90 days) closely followed by n_2g_2 (116.20 days). In the second year, the effect remained similar, onset of senescence was prolonged maximum (120 days) in n_1g_2 but, on par with n_2g_2 (117.60).

4.1.2.8 Biomass Partitioning at the Start of Senescence

Method of planting and combination of nutrient management + growth promoter recorded significant variations in the percentage biomass accumulated in Chinese potato plants during both the years (Tables 17a and 17b). Irrespective of the treatments, maximum partitioning in the plant occurred to the tubers and the lowest to the leaves. Stem biomass was significantly higher (36.33 and 36.57 %) in m_3 during both the years and was on par with m_1. Ridge method of planting at a spacing of 30 cm x 30 cm (m_4) significantly increased the leaf biomass (7.97 %) and was on par with m_2 during both the years (7.89 and 7.94 %). Tuber biomass also followed the same trend with m_4 producing significantly higher values (74.61 and 74.96 %) comparable with m_2.

Nutrient management and growth promoter combination failed to produce significant variation in stem and leaf biomass. The treatment n_1g_1 recorded significantly higher tuber biomass (68.88 %) during first year alone.

Interactions failed to bring marked variation in stem, leaf and tuber biomass during both the years (Table 17b).

4.1.3 Yield Attributes and Yield

Yield attributes in Chinese potato *viz.*, number of tubers per plant, average tuber weight, per plant tuber yield and marketable tuber yield were recorded at harvest and the per hectare tuber yield, marketable tuber yield, percentage marketable tuber yield and harvest index were computed and the statistically analysed data are presented in Tables 18 to 20.

4.1.3.1 Number of Tubers per Plant

The number of tubers per plant varied with the method of planting and the combination of nutrient management + growth promoter used in the experiment (Table 18a and 18b).

Planting on beds at 30 cm x 30 cm spacing (m_2) resulted in the maximum number of tubers per plant during both the years (20.4 and 22.5 respectively) and it was the lowest in ridge method at closer spacing. Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) recorded the significantly highest tuber number in both the years (21.8 and 20.9 respectively). Assessing the interaction effects, the treatment combination involving ridge method of planting at 30 cm x 30 cm along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid ($m_4n_1g_1$) produced the maximum number of tubers per plant (23.8) in the first year and was on par with $m_2n_1g_1$ (23.6). During second year, it was the

Table 16a. Effect of method of planting and nutrient management x growth promoter on days to senescence

Treatments	Days to senescence	
	2019-20	2020-21
Method of planting		
m_1 - Bed method (30 cm x 15 cm)	114.17	116.29
m_2 - Bed method (30 cm x 30 cm)	116.25	117.38
m_3 - Ridge method (30 cm x 15 cm)	113.33	115.00
m_4 - Ridge method (30 cm x 30 cm)	115.83	116.58
m_5 - Mound method (30 cm x 30 cm)	113.04	113.67
SEm (±)	1.80	1.69
CD (0.05)	NS	NS
Nutrient management x growth promoter		
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	113.80	115.25
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	118.90	120.00
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	113.70	115.15
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	114.00	114.95
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	116.20	117.60
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	110.55	111.75
SEm (±)	1.49	1.55
CD (0.05)	4.184	4.378

Table 16b. Interaction effect of method of planting and combination of nutrient management + growth promoter on days to senescence

Treatments	Days to senescence	
	2019-20	2020-21
$m_1n_1g_1$	113.00	115.50
$m_1n_1g_2$	119.50	121.50
$m_1n_1g_3$	108.75	111.00
$m_1n_2g_1$	110.75	111.50
$m_1n_2g_2$	119.25	122.50
$m_1n_2g_3$	113.75	115.75
$m_2n_1g_1$	114.50	115.75
$m_2n_1g_2$	119.25	120.25
$m_2n_1g_3$	117.00	118.25
$m_2n_2g_1$	115.50	116.50
$m_2n_2g_2$	119.00	120.00
$m_2n_2g_3$	112.25	113.50
$m_3n_1g_1$	113.25	114.75
$m_3n_1g_2$	117.00	118.50
$m_3n_1g_3$	114.75	116.75
$m_3n_2g_1$	110.25	111.50
$m_3n_2g_2$	116.75	118.25
$m_3n_2g_3$	108.00	110.25
$m_4n_1g_1$	113.50	114.50
$m_4n_1g_2$	119.50	120.00
$m_4n_1g_3$	114.75	115.50
$m_4n_2g_1$	116.75	117.50
$m_4n_2g_2$	119.00	119.50
$m_4n_2g_3$	111.50	112.50
$m_5n_1g_1$	114.75	115.75
$m_5n_1g_2$	119.25	119.75
$m_5n_1g_3$	113.25	114.25
$m_5n_2g_1$	116.75	117.75
$m_5n_2g_2$	107.00	107.75
$m_5n_2g_3$	107.25	106.75
SEm (±)	3.53	3.59
CD (0.05)	NS	NS

Table 17a. Effect of method of planting and nutrient management x growth promoter on biomass partitioning, per cent

Treatments	Biomass partitioning					
	2019-20			2020-21		
	Stem	Leaf	Tuber	Stem	Leaf	Tuber
Method of planting						
m_1 - Bed method (30 cm x 15 cm)	35.18 (33.34)	14.43 (6.21)	51.05 (60.47)	35.28 (33.61)	14.56 (6.32)	50.91 (60.18)
m_2 - Bed method (30 cm x 30 cm)	24.85 (17.72)	16.31 (7.89)	59.60 (74.39)	24.74 (17.66)	16.36 (7.94)	60.06 (74.76)
m_3 - Ridge method (30 cm x 15 cm)	37.00 (36.33)	14.17 (6.00)	49.39 (57.60)	37.16 (36.57)	14.22 (6.04)	49.30 (57.45)
m_4 - Ridge method (30 cm x 30 cm)	25.61 (18.75)	16.39 (7.97)	59.76 (74.61)	24.51 (17.36)	16.39 (7.97)	60.10 (74.96)
m_5 - Mound method (30 cm x 30 cm)	27.47 (21.37)	15.83 (7.45)	57.55 (71.18)	27.42 (21.33)	15.88 (7.49)	57.69 (71.35)
SEm (±)	1.43	0.08	0.31	1.60	0.12	0.68
CD (0.05)	4.423	0.250	0.94	4.940	0.372	2.100
Nutrient management x growth promoter						
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	29.12 (24.12)	15.64 (7.29)	56.20 (68.88)	28.95 (23.92)	15.63 (7.28)	56.35 (68.96)
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	30.26 (25.89)	15.36 (7.04)	55.24 (67.27)	30.09 (25.67)	15.46 (7.13)	55.38 (67.36)
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1+ Water spray	30.84 (26.71)	15.34 (7.02)	54.79 (66.53)	30.54 (26.34)	15.40 (7.08)	55.03 (66.81)
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	30.16 (25.71)	15.44 (7.11)	55.54 (67.75)	29.78 (25.30)	15.46 (7.13)	55.70 (67.84)
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	30.20 (25.78)	15.36 (7.05)	55.32 (67.40)	30.09 (25.80)	15.43 (7.11)	55.20 (67.13)
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	29.56 (24.80)	15.43 (7.11)	55.72 (68.07)	29.50 (24.81)	15.50 (7.18)	56.01 (68.35)
SEm (±)	0.40	0.08	0.32	0.58	0.14	0.85
CD (0.05)	NS	NS	0.91	NS	NS	NS

Figures in parenthesis are mean of original values; Data subjected to arcsine transformation

Table 17b. Interaction effect of method of planting and combination of nutrient management + growth promoter on biomass partitioning, per cent

Treatments	Biomass partitioning					
	2019-20			2020-21		
	Stem	Leaf	Tuber	Stem	Leaf	Tuber
$m_1n_1g_1$	32.73 (29.41)	14.78 (6.51)	53.26 (64.22)	33.03 (29.96)	15.01 (6.71)	52.70 (63.28)
$m_1n_1g_2$	35.10 (33.15)	14.33 (6.12)	51.18 (60.70)	35.39 (33.80)	14.58 (6.34)	50.66 (59.81)
$m_1n_1g_3$	36.53 (35.54)	14.35 (6.14)	49.75 (58.25)	36.52 (35.60)	14.38 (6.17)	49.84 (58.35)
$m_1n_2g_1$	35.85 (34.42)	14.47 (6.25)	50.37 (59.31)	36.00 (34.82)	14.46 (6.23)	50.26 (59.06)
$m_1n_2g_2$	36.35 (35.25)	14.22 (6.04)	50.05 (58.76)	36.38 (35.43)	14.39 (6.19)	49.88 (58.42)
$m_1n_2g_3$	34.49 (32.30)	14.43 (6.21)	51.69 (61.56)	34.34 (32.05)	14.53 (6.30)	52.09 (62.17)
$m_2n_1g_1$	24.15 (16.92)	16.44 (8.01)	60.05 (75.08)	24.13 (16.82)	16.44 (8.02)	60.80 (75.79)
$m_2n_1g_2$	24.43 (17.26)	16.31 (7.88)	59.90 (74.83)	24.47 (17.23)	16.36 (7.95)	60.37 (75.12)
$m_2n_1g_3$	25.69 (18.79)	16.16 (7.74)	59.00 (73.46)	25.50 (18.66)	16.21 (7.79)	59.12 (73.60)
$m_2n_2g_1$	25.07 (17.98)	16.25 (7.83)	59.48 (74.19)	24.96 (17.89)	16.32 (7.90)	59.89 (74.52)
$m_2n_2g_2$	24.76 (17.55)	16.29 (7.87)	59.73 (74.58)	24.53 (17.53)	16.33 (7.91)	59.86 (74.63)
$m_2n_2g_3$	24.98 (17.83)	16.43 (8.00)	59.46 (74.17)	24.86 (17.85)	16.50 (8.07)	60.30 (74.91)
$m_3n_1g_1$	35.72 (34.18)	14.50 (6.27)	50.44 (59.43)	35.85 (34.39)	14.50 (6.27)	50.32 (59.18)
$m_3n_1g_2$	37.59 (37.41)	14.15 (5.97)	48.83 (56.61)	37.35 (36.87)	14.23 (6.05)	49.08 (57.09)
$m_3n_1g_3$	37.32 (36.84)	14.20 (6.02)	49.03 (56.97)	37.24 (36.67)	14.25 (6.07)	49.25 (57.35)
$m_3n_2g_1$	37.12 (36.50)	14.24 (6.05)	49.27 (57.43)	37.40 (36.91)	14.22 (6.03)	49.14 (57.19)
$m_3n_2g_2$	37.32 (36.88)	14.02 (5.88)	49.15 (57.21)	38.11 (38.19)	14.10 (5.94)	48.43 (55.96)
$m_3n_2g_3$	36.90 (36.16)	13.92 (5.79)	49.61 (57.95)	37.01 (36.42)	14.03 (5.90)	49.61 (57.92)
$m_4n_1g_1$	24.65 (17.52)	16.72 (8.28)	60.47 (75.70)	23.43 (15.85)	16.41 (7.99)	60.88 (76.25)
$m_4n_1g_2$	25.56 (18.66)	16.28 (7.86)	59.68 (74.51)	24.62 (17.50)	16.34 (7.93)	60.02 (74.88)
$m_4n_1g_3$	25.68 (18.82)	16.32 (7.90)	59.88 (74.79)	24.52 (17.30)	16.41 (8.01)	60.50 (75.39)
$m_4n_2g_1$	25.74 (18.91)	16.44 (8.02)	60.62 (75.93)	23.57 (16.24)	16.51 (8.08)	61.12 (76.42)
$m_4n_2g_2$	25.82 (18.99)	16.28 (7.86)	59.54 (74.29)	24.79 (17.66)	16.30 (7.89)	59.67 (74.45)
$m_4n_2g_3$	26.22 (19.62)	16.30 (7.89)	58.33 (72.43)	26.15 (19.61)	16.35 (7.94)	58.41 (72.35)
$m_5n_1g_1$	28.34 (22.57)	15.78 (7.40)	56.77 (69.97)	28.29 (22.58)	15.80 (7.41)	57.05 (70.29)
$m_5n_1g_2$	28.62 (22.97)	15.72 (7.34)	56.59 (69.68)	28.60 (22.95)	15.77 (7.40)	56.76 (69.88)
$m_5n_1g_3$	28.97 (23.56)	15.66 (7.29)	56.28 (69.17)	28.91 (23.49)	15.73 (7.35)	56.42 (69.35)
$m_5n_2g_1$	27.01 (20.73)	15.79 (7.40)	57.97 (71.87)	26.95 (20.63)	15.81 (7.43)	58.09 (71.98)
$m_5n_2g_2$	26.73 (20.24)	16.01 (7.60)	58.15 (72.15)	26.62 (20.18)	16.05 (7.64)	58.17 (72.18)
$m_5n_2g_3$	25.18 (18.12)	16.05 (7.64)	59.51 (74.24)	25.14 (18.13)	16.11 (7.71)	59.66 (74.42)
SEm (±)	0.90	0.18	0.32	1.29	0.31	1.90
CD (0.05)	NS	NS	NS	NS	NS	NS

Figures in parenthesis are mean of original values; Data subjected to arcsine transformation highest (25) in $m_2n_1g_1$. Significantly the lowest number of tubers was produced in $m_4n_2g_3$ (15.7) during first year and in $m_3n_2g_3$ (14.3) during second year.

4.1.3.2 Average Tuber Weight

The significant variations induced in the average tuber weight due to the treatments are evident from the data in Tables 18a and 18b. The main plot and sub plot treatments exerted significant influence in both the years. In the first year, bed planting at 30 cm x 30 cm (m_2) recorded a higher tuber weight (9.55 g) and was on par with ridge method of planting (m_4) at 30 cm x 30 cm spacing (9.42 g). In the second year, m_2, m_4 and m_5 were on par with values 10.03, 10.01 and 9.87 respectively. The subplot effects exhibited the highest average tuber weight in the nutrient combination with PGPR Mix 1 and humic acid (n_1g_1) during both the years (9.22 and 9.74 g respectively). There was no significant variation in average tuber weight due to the interactions in both of the years.

4.1.3.3 Tuber Yield per Plant

Perusal of data in Table 18a and 18b revealed the significant influence of the treatments on tuber yield per plant during both the years of experimentation. Per plant yields were higher at the wider spacing and the bed method (m_2) and significantly superior during both the years (165.17 and 172.27 g per plant respectively). Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid registered the statically superior yield in both the years (150.32 and 155.48 g per plant respectively). The interaction effect of the planting methods and nutrient and growth promoter combination revealed significant variations and the combination $m_2n_1g_1$ (189.48 g) recorded the highest tuber yield per plant, on par with $m_4n_1g_1$ (182.19 g) in the first year. In the second year it was the highest in $m_2n_1g_1$ (198.95 g). The significantly lowest tuber yields were in $m_3n_2g_3$ (83.32 g and 87.02 g) in both the years.

4.1.3.4 Marketable Tuber Yield per Plant

The data on marketable tuber yield per plant as influenced by methods of planting, combination of nutrient management and growth promoter in the two years are presented in Tables 18a and 18b. Significant differences due to the treatments were observed in both the years. Bed method of planting at 30 cm x 30 cm spacing (m_2) led to the significantly highest marketable tuber yield in both the years (141.12 and 149.04 g per plant) and the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid was superior (126.32 and 133.80 g per plant in first and second year).

Analysis of data on the interaction effects of the treatments (Table 18b) revealed that the treatment combination $m_2n_1g_1$ to accrue the significantly highest marketable tuber yields during both the years of experimentation (170.37 and 179.45 g respectively). It was significantly the lowest in $m_3n_2g_3$ (64.83 g and 67.55 g) during both the years.

4.1.3.5 Percentage Marketable Tubers per Plant

The variations in percentage marketable tubers per plant due to methods of planting and combination of nutrient management and growth promoter are presented in Tables 19a and 19b.

The percentage of marketable tuber per plant varied significantly with the treatments in both the years. In the first year, ridge method of planting at 30 cm x 30 cm spacing (m_4) recorded a higher percentage of marketable tubers (63.92 %), statistically similar to m_2, bed method of planting at 30 cm x 30 cm spacing (62.73 %). In the second year, mound method with 30 cm x 30 cm spacing recorded the significantly highest percentage of marketable tuber per plant (55.91 %). Among the sub plot treatment, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) recorded a higher percentage (65.65 %), while it was on par with n_1g_2 in the first year. During the second year of study, the significantly superior percentage of tuber per plant was observed in n_1g_1 (64.27 %).

Table 18a. Effect of method of planting and nutrient management x growth promoter on yield attributes

Treatments	Number of tubers per plant		Average tuber weight (g)		Tuber yield per plant (g)		Marketable tuber yield per plant (g)	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Method of planting								
m_1 - Bed method (30 cm x 15 cm)	18.5	15.8	7.48	8.03	97.98	102.19	76.18	80.96
m_2 - Bed method (30 cm x 30 cm)	20.4	22.5	9.55	10.03	165.17	172.27	141.12	149.04
m_3 - Ridge method (30 cm x 15 cm)	17.7	15.0	7.47	8.06	91.51	94.47	70.66	74.82
m_4 - Ridge method (30 cm x 30 cm)	19.5	21.8	9.42	10.01	159.23	165.00	132.41	140.28
m_5 - Mound method (30 cm x 30 cm)	19.1	20.5	9.26	9.87	146.56	152.73	119.00	125.94
SEm (±)	0.20	0.09	0.06	0.09	1.11	1.21	1.49	0.89
CD (0.05)	0.613	0.289	0.187	0.264	3.432	3.735	4.604	2.756
Nutrient management x growth promoter								
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	21.8	20.9	9.22	9.74	150.32	155.48	126.32	133.80
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	20.3	19.7	8.91	9.50	139.52	144.05	115.15	121.85
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	18.6	19.1	8.67	9.25	132.28	137.64	108.30	114.96
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	19.3	18.8	8.54	9.12	128.37	134.16	104.21	110.26
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	18.1	18.3	8.38	8.94	123.07	128.44	99.04	104.63
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	16.4	17.9	8.10	8.65	118.97	124.21	94.21	99.76
SEm (±)	0.3	0.1	0.07	0.08	1.22	1.43	1.41	0.89
CD (0.05)	0.76	0.33	0.196	0.217	3.440	4.030	3.984	2.518

Table 18b. Interaction effect of method of planting and combination of nutrient management + growth promoter on yield attributes

Treatments	Number of tubers per plant		Average tuber weight (g)		Tuber yield per plant (g)		Marketable tuber yield per plant (g)	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
$m_1n_1g_1$	20.5	17.5	8.04	8.39	114.34	117.63	89.69	96.38
$m_1n_1g_2$	19.9	16.3	7.92	8.20	102.29	107.50	80.46	86.53
$m_1n_1g_3$	17.7	15.7	7.53	8.11	96.28	101.13	75.69	80.19
$m_1n_2g_1$	20.0	15.6	7.40	7.96	96.04	100.75	74.60	79.04
$m_1n_2g_2$	16.9	15.1	7.26	7.79	91.65	95.19	71.00	74.17
$m_1n_2g_3$	16.3	14.7	6.75	7.70	87.30	90.93	65.63	69.43
$m_2n_1g_1$	23.6	25.0	10.45	10.68	189.48	198.95	170.37	179.45
$m_2n_1g_2$	21.9	23.4	9.84	10.30	175.76	182.14	153.89	161.03
$m_2n_1g_3$	21.6	22.4	9.59	10.03	165.32	171.58	139.30	148.65
$m_2n_2g_1$	19.5	21.8	9.40	9.92	158.12	165.15	133.58	140.76
$m_2n_2g_2$	19.7	21.3	9.24	9.73	153.21	160.02	127.46	134.56
$m_2n_2g_3$	16.0	20.9	8.76	9.53	149.12	155.75	122.09	129.81
$m_3n_1g_1$	19.2	16.0	7.78	8.68	101.18	104.25	79.09	84.67
$m_3n_1g_2$	17.7	15.2	7.70	8.55	95.62	96.75	73.07	77.42
$m_3n_1g_3$	17.5	15.0	7.53	8.11	92.18	94.19	70.28	74.46
$m_3n_2g_1$	17.9	15.0	7.40	7.96	90.60	94.63	70.38	74.57
$m_3n_2g_2$	17.7	14.6	7.24	7.82	86.14	89.97	66.32	70.27
$m_3n_2g_3$	16.1	14.3	7.15	7.24	83.32	87.02	64.83	67.55
$m_4n_1g_1$	23.8	23.8	10.00	10.48	182.19	186.90	153.52	162.64
$m_4n_1g_2$	20.8	22.6	9.65	10.38	170.84	174.00	141.61	150.04
$m_4n_1g_3$	20.1	22.0	9.45	10.17	159.93	167.04	135.48	143.54
$m_4n_2g_1$	18.5	21.4	9.30	9.96	154.10	160.95	127.84	135.45
$m_4n_2g_2$	18.2	20.7	9.14	9.77	147.11	153.65	121.17	128.38
$m_4n_2g_3$	15.7	20.1	8.95	9.32	141.18	147.46	114.82	121.65
$m_5n_1g_1$	21.8	22.2	9.82	10.49	164.43	169.65	138.94	145.84
$m_5n_1g_2$	21.0	21.0	9.43	10.06	153.06	159.87	126.71	134.25
$m_5n_1g_3$	16.0	20.7	9.24	9.85	147.68	154.25	120.76	127.95
$m_5n_2g_1$	20.4	20.3	9.18	9.78	142.98	149.34	114.67	121.49
$m_5n_2g_2$	17.9	19.7	9.02	9.60	137.27	143.37	109.25	115.75
$m_5n_2g_3$	17.8	19.4	8.89	9.46	133.92	139.87	103.69	110.36
SEm (±)	0.6	0.3	0.15	0.18	2.73	3.16	3.25	2.03
CD (0.05)	1.70	0.73	NS	NS	7.691	9.012	8.909	5.631

Table 19a. Effect of method of planting and nutrient management x growth promoter on yield attributes and yield

Treatments	Percentage marketable tubers per plant		Tuber yield (t ha^{-1})		
	2019-20	2020-21	2019-20	2020-21	Pooled mean
Method of planting					
m_1 - Bed method (30 cm x 15 cm)	55.00	50.86	20.18	19.76	20.93
m_2 - Bed method (30 cm x 30 cm)	62.73	53.56	17.28	16.19	17.54
m_3 - Ridge method (30 cm x 15 cm)	52.45	51.33	18.60	18.67	19.45
m_4 - Ridge method (30 cm x 30 cm)	63.92	50.50	17.82	15.50	17.51
m_5 - Mound method (30 cm x 30 cm)	59.76	55.91	16.58	14.58	16.19
SEm (±)	0.79	0.45	0.10	0.10	0.23
CD (0.05)	2.422	1.380	0.302	0.294	0.659
Nutrient management x growth promoter					
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	65.65	64.27	19.92	20.28	20.10
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	63.35	57.04	19.05	19.40	19.23
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	61.02	52.76	18.29	18.84	18.56
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	58.80	49.33	17.70	18.29	18.00
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	52.88	47.01	17.23	17.60	17.41
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	50.93	44.17	16.37	16.94	16.65
SEm (±)	1.15	0.63	0.12	0.10	0.09
CD (0.05)	3.234	1.769	0.332	0.283	0.250

Table 19b. Interaction effect of method of planting and combination of nutrient management + growth promoter on yield attributes and yield

Treatments	Percentage marketable tubers per plant		Tuber yield (t ha^{-1})		
	2019-20	2020-21	2019-20	2020-21	Pooled mean
$m_1n_1g_1$	60.03	58.52	22.84	23.92	23.38
$m_1n_1g_2$	58.69	56.29	21.19	22.78	21.99
$m_1n_1g_3$	57.32	51.41	20.08	21.69	20.89
$m_1n_2g_1$	55.71	48.49	19.27	21.28	20.27
$m_1n_2g_2$	49.62	47.47	19.02	20.71	19.87
$m_1n_2g_3$	48.62	42.97	18.67	19.76	19.21
$m_2n_1g_1$	73.06	70.67	18.82	19.88	19.35
$m_2n_1g_2$	69.25	60.01	18.42	18.62	18.52
$m_2n_1g_3$	67.08	55.42	17.05	17.95	17.50
$m_2n_2g_1$	66.08	46.64	17.35	17.35	17.35
$m_2n_2g_2$	50.47	45.40	16.32	16.82	16.57
$m_2n_2g_3$	50.45	43.22	15.72	16.19	15.96
$m_3n_1g_1$	56.94	56.93	21.48	22.06	21.77
$m_3n_1g_2$	54.49	55.73	20.11	21.17	20.64
$m_3n_1g_3$	53.62	53.49	19.40	20.49	19.94
$m_3n_2g_1$	52.51	51.19	17.84	20.14	18.99
$m_3n_2g_2$	50.86	46.29	17.61	19.27	18.44
$m_3n_2g_3$	46.27	44.35	15.15	18.67	16.91
$m_4n_1g_1$	70.98	68.60	18.57	18.82	18.69
$m_4n_1g_2$	67.15	53.35	18.20	18.11	18.16
$m_4n_1g_3$	64.94	47.77	17.96	17.67	17.82
$m_4n_2g_1$	61.64	45.62	17.71	16.99	17.35
$m_4n_2g_2$	60.89	43.92	17.30	16.18	16.74
$m_4n_2g_3$	57.91	43.75	17.14	15.50	16.32
$m_5n_1g_1$	67.22	66.63	17.88	16.74	17.31
$m_5n_1g_2$	67.16	59.84	17.34	16.32	16.83
$m_5n_1g_3$	62.14	55.73	16.93	16.37	16.65
$m_5n_2g_1$	58.09	54.73	16.34	15.69	16.01
$m_5n_2g_2$	52.58	51.97	15.86	15.03	15.45
$m_5n_2g_3$	51.38	46.56	15.15	14.58	14.87
SEm (±)	2.47	1.36	0.26	0.23	0.20
CD (0.05)	NS	3.957	0.743	0.634	0.558

There was no marked variation in percentage of marketable tubers due to interaction effect of treatments in the first year, while in the second year, it was maximum in $m_2n_1g_1$ (70.67 %) and the lowest in $m_1n_2g_3$ (42.97 %).

4.1.3.6 Tuber Yield ha^{-1}

The data on per hectare tuber yields as influenced by methods of planting and combination of nutrient management and growth promoter in the two years of experimentation are given in Tables 19a and 19b.

There was significant variation in tuber yield due to methods of planting in both the years. Tuber yield was the highest in bed method with planting at 30 cm x 15 cm spacing (m_1) during both the years. The yields were 20.18 and 19.76 t ha^{-1} respectively and significantly superior. In the case of sub plot effects, during both the years, the combination, 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) produced the significantly highest tuber yields (19.92 and 20.28 t ha^{-1} respectively).

Perusal of the data on interaction effects revealed the significantly superior yield in treatment combination $m_1n_1g_1$ in both the years (22.84 and 23.92 t ha^{-1} respectively). However, the yields recorded in $m_3n_2g_3$ and $m_5n_2g_3$ (15.15 t ha^{-1}) during first year and in $m_5n_2g_3$ (14.58 t ha^{-1}) during the second year were significantly the lowest. Results of pooled analysis revealed the same trend with $m_1n_1g_1$ producing the maximum per hectare tuber yield of 23.38 t ha^{-1}.

4.1.3.7 Marketable Tuber Yield ha^{-1}

The significant influence of the treatments on marketable tuber yield in the two years are detailed in Tables 20a and 20b. Significantly the highest marketable tuber yields in both the years (16.93 and 17.99 t ha^{-1} respectively) were adjudged in the bed method of planting at 30 cm x 15 cm spacing (m_1). Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) was superior, irrespective of the year of study (17.54 and 18.34 t ha^{-1} respectively).

The per hectare marketable tuber yield was significantly influenced by interactions of main plot and sub plot treatments. The yield was maximum in $m_1n_1g_1$ in both of the years (19.93 and 21.42 t ha^{-1} respectively) and the lowest in $m_5n_2g_3$ (11.52 and 12.26 t ha^{-1} respectively). Results of pooled analysis revealed significantly higher marketable tuber yield per ha (20.67 t ha^{-1}) with the treatment combination $m_1n_1g_1$.

4.1.3.8 Percentage marketable tuber yield

The data on percentage marketable tuber yield as influenced by methods of planting and combination of nutrient management and growth promoter in the two years of experimentation are given in Tables 20a and 20b.

Bed method of planting at 30 cm x 30 cm spacing (m_2) led to the significantly highest value of percentage marketable tuber yield in both the years (89.40 and 91.28 %) and was comparable with m_4 in the second year. The application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid resulted in highest value of percentage marketable tuber yield (88.27 and 90.74 % in first and second year) and on par with n_1g_2 in the second year. Interaction effect was significant in the first year alone with highest value in $m_2n_1g_1$.

4.1.3.9 Harvest Index

The data on effect of methods of planting and nutrient management + growth promoter on harvest index is given in Table 20a and 20b. Ridge and bed method of planting with a spacing of 30 cm x 30 cm recorded the highest harvest index in both the years (0.74 and 0.78).

Sub plot effect was found significant only in the first year of study. Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid recorded the significantly highest value (0.69) and it was on par with n_2g_3 (0.68). The interaction effects were non-significant in both the years.

Table 20a. Effect of method of planting and nutrient management x growth promoter on marketable tuber yield, percentage marketable tuber yield and harvest index

Treatments	Marketable tuber yield (t ha^{-1})			Percentage marketable tuber yield		Harvest index	
	2019-20	2020-21	Pooled mean	2019-20	2020-21	2019-20	2020-21
Method of planting							
m_1 - Bed method (30 cm x 15 cm)	16.93	17.99	17.46	83.83	82.76	0.60	0.63
m_2 - Bed method (30 cm x 30 cm)	15.47	16.27	15.87	89.40	91.28	0.74	0.78
m_3 - Ridge method (30 cm x 15 cm)	15.58	16.63	16.10	84.17	81.86	0.58	0.61
m_4 - Ridge method (30 cm x 30 cm)	14.71	15.34	15.02	82.47	89.05	0.74	0.78
m_5 - Mound method (30 cm x 30 cm)	13.22	13.91	13.57	79.60	88.11	0.71	0.73
SEm (±)	0.12	0.16	0.10	0.91	0.89	0.006	0.01
CD (0.05)	0.372	0.480	0.287	2.814	2.741	0.0181	.018
Nutrient management x growth promoter							
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	17.54	18.34	17.94	88.27	90.74	0.69	0.69
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	16.21	16.98	16.59	85.13	88.02	0.67	0.70
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1+ Water spray	15.28	16.21	15.74	83.68	86.44	0.66	0.71
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	14.80	15.66	15.23	83.54	85.96	0.67	0.71
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	14.06	14.83	14.45	81.61	84.70	0.67	0.71
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	13.22	14.13	13.67	81.11	83.81	0.68	0.72
SEm (±)	0.10	0.14	0.08	0.83	0.95	0.005	0.01
CD (0.05)	0.295	0.383	0.230	2.333	2.672	0.0133	NS

Table 20b. Interaction effect of method of planting and combination of nutrient management + growth promoter on marketable tuber yield, percentage marketable tuber yield and harvest index

Treatments	Marketable tuber yield (t ha^{-1})			Percentage marketable tuber yield		Harvest index	
	2019-20	2020-21	Pooled mean	2019-20	2020-21	2019-20	2020-21
$m_1n_1g_1$	19.93	21.42	20.67	87.30	89.55	0.64	0.64
$m_1n_1g_2$	17.88	19.23	18.56	84.38	84.45	0.61	0.63
$m_1n_1g_3$	16.82	17.82	17.32	83.80	82.27	0.58	0.63
$m_1n_2g_1$	16.58	17.56	17.07	86.09	82.57	0.59	0.62
$m_1n_2g_2$	15.78	16.48	16.13	83.03	79.59	0.59	0.63
$m_1n_2g_3$	14.58	15.43	15.01	78.39	78.12	0.62	0.64
$m_2n_1g_1$	17.68	18.69	18.19	93.94	94.02	0.75	0.75
$m_2n_1g_2$	17.10	17.39	17.25	92.82	93.40	0.75	0.77
$m_2n_1g_3$	15.48	16.52	16.00	90.92	92.02	0.73	0.77
$m_2n_2g_1$	14.84	15.64	15.24	85.61	90.26	0.74	0.78
$m_2n_2g_2$	14.16	14.95	14.56	86.81	88.87	0.75	0.79
$m_2n_2g_3$	13.57	14.42	14.00	86.28	89.09	0.74	0.79
$m_3n_1g_1$	17.58	18.82	18.20	81.85	85.32	0.59	0.63
$m_3n_1g_2$	16.24	17.20	16.72	80.77	81.34	0.57	0.62
$m_3n_1g_3$	15.62	16.55	16.09	80.50	80.74	0.57	0.62
$m_3n_2g_1$	15.64	16.57	16.11	87.69	82.29	0.57	0.61
$m_3n_2g_2$	14.74	15.62	15.18	83.82	81.05	0.57	0.60
$m_3n_2g_3$	13.66	15.01	14.34	90.38	80.40	0.58	0.60
$m_4n_1g_1$	17.06	17.07	17.07	91.91	90.73	0.75	0.76
$m_4n_1g_2$	15.73	16.17	15.95	86.44	89.30	0.74	0.78
$m_4n_1g_3$	15.05	15.95	15.50	83.88	90.27	0.74	0.79
$m_4n_2g_1$	14.20	15.05	14.63	80.33	88.61	0.74	0.80
$m_4n_2g_2$	13.46	14.26	13.86	77.81	88.19	0.73	0.78
$m_4n_2g_3$	12.76	13.52	13.14	74.43	87.23	0.72	0.79
$m_5n_1g_1$	15.44	15.70	15.57	86.35	94.09	0.70	0.69
$m_5n_1g_2$	14.08	14.92	14.50	81.25	91.61	0.70	0.71
$m_5n_1g_3$	13.42	14.22	13.82	79.30	86.88	0.69	0.74
$m_5n_2g_1$	12.74	13.50	13.12	77.99	86.05	0.72	0.74
$m_5n_2g_2$	12.14	12.86	12.50	76.60	85.81	0.72	0.76
$m_5n_2g_3$	11.52	12.26	11.89	76.08	84.21	0.74	0.76
SEm (±)	0.25	0.32	0.18	1.92	2.13	0.01	0.12
CD (0.05)	0.660	0.857	0.516	5.217	NS	NS	NS

4.1.4 Quality Attributes of Tuber

The quality characters of tuber *viz.* sucrose, starch and protein content were analysed at harvest and the results are depicted in Tables 21a and 21b.

4.1.4.1 Sucrose Content

Perusal of data in Tables 21a and 21b revealed that, there was no variation in sucrose content due to main plot, sub plot and interaction in both the years under study.

4.1.4.2 Starch Content

There was no significant variation in the starch content due to methods of planting and the interaction of the treatments in both the years. The sub plot effect alone was significant. Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) produced the significantly highest starch content in both the years (73.24 and 77.02 % respectively).

4.1.4.3 Protein Content

Protein content also showed a similar trend of the influence of nutrient + growth promoter combination, it alone being significant (Tables 21a and 21b). Amongst the sub plot treatments, the combination of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid produced the significantly higher protein content, 7.71 and 7.94 per cent in the first and second year respectively.

4.1.5 Plant Analysis

4.1.5.1 Uptake of NPK

Tables 22a and 22b depict the effect of methods of planting and combination of nutrient management and growth promoter on total N, P and K uptake in both the years. There was significant variation in the nutrient uptake due to treatments. Bed method and planting at 30 cm x 15 cm spacing recorded the significantly highest N, P and K uptake during both the years (76.39 kg N, 25.97 kg P and 148.17 kg K ha^{-1} in the first year and 82.48 kg N, 25.89 kg P and 173.96 kg K ha^{-1} in the second year respectively). N and K uptake in m_1 were superior but the P uptake in m_1 was on par with m_3 during the second year. With respect to the sub plot effects, the significantly highest N, P and K uptake were observed in the combination, 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid during both the years and remained superior to all other combinations.

The statistical analysis of data on the interaction effects revealed that N and P uptake computed were comparable during both years, while in K, the variations were significant. Potassium uptake was the highest in $m_1n_1g_1$ (170.49 and 188.85 kg ha^{-1}) in both years, but in the second year, it was on par with $m_1n_1g_2$ (182.64 kg ha^{-1}).

4.1.6 Soil Analysis

4.1.6.1 Soil pH

Perusal of the data in Tables 23a and 23b revealed that there was no marked differences in soil pH either due to the main plot (method of planting) or subplot (nutrient management + growth promoter) treatments in both the years. The interaction also did not record any significant variation in soil pH in both the years of experimentation.

4.1.6.2 Organic Carbon

Tables 23a and 23b depict the effect of method of planting and combination of nutrient management and growth promoter on soil organic carbon after the experiment in both the years. There was no significant variation in organic carbon with either the main and sub plot treatments or the interactions in both the years.

Table 21a. Effect of method of planting and nutrient management x growth promoter on tuber quality

Treatments	Sucrose (mg g^{-1})		Starch (%)		Protein (%)	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Method of planting						
m_1 - Bed method (30 cm x 15 cm)	3.04	2.85	68.96	72.07	7.16	7.56
m_2 - Bed method (30 cm x 30 cm)	3.05	2.95	66.77	69.10	7.00	7.21
m_3 - Ridge method (30 cm x 15 cm)	3.03	2.70	68.38	72.90	7.16	7.47
m_4 - Ridge method (30 cm x 30 cm)	3.04	2.95	65.12	69.54	6.75	7.00
m_5 - Mound method (30 cm x 30 cm)	3.05	2.86	66.54	71.56	7.01	7.20
SEm (±)	0.05	0.05	0.93	0.89	0.08	0.14
CD (0.05)	NS	NS	NS	NS	NS	NS
Nutrient management x growth promoter						
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	3.06	2.91	73.24	77.02	7.71	7.94
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	3.06	2.93	68.51	74.11	7.18	7.50
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	3.08	2.86	67.36	72.32	6.98	7.33
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	3.06	2.85	66.29	69.62	6.97	7.25
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	3.03	2.77	64.36	67.48	6.73	7.00
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	2.95	2.84	63.16	65.65	6.53	6.71
SEm (±)	0.05	0.05	1.02	0.93	0.10	0.10
CD (0.05)	NS	NS	2.871	2.632	0.271	0.285

Table 21b. Interaction effect of method of planting and combination of nutrient management + growth promoter on tuber quality

Treatments	Sucrose (mg g^{-1})		Starch (%)		Protein (%)	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
$m_1n_1g_1$	3.11	2.98	74.39	77.23	7.74	8.15
$m_1n_1g_2$	3.03	2.95	71.87	74.24	7.35	7.87
$m_1n_1g_3$	3.03	2.99	69.22	72.71	7.06	7.58
$m_1n_2g_1$	3.06	2.69	68.36	71.80	7.18	7.49
$m_1n_2g_2$	3.08	2.76	66.03	69.36	6.94	7.23
$m_1n_2g_3$	2.91	2.74	63.88	67.11	6.71	7.00
$m_2n_1g_1$	3.16	3.08	75.97	76.46	7.98	7.98
$m_2n_1g_2$	3.03	2.94	68.67	71.87	7.31	7.50
$m_2n_1g_3$	3.05	2.89	68.88	69.72	6.97	7.27
$m_2n_2g_1$	3.00	2.90	64.07	67.30	6.81	7.02
$m_2n_2g_2$	3.06	2.95	62.45	65.60	6.56	6.84
$m_2n_2g_3$	3.00	2.94	60.57	63.63	6.36	6.64
$m_3n_1g_1$	3.13	2.85	73.70	78.62	7.66	7.99
$m_3n_1g_2$	3.00	2.79	68.87	75.08	7.23	7.55
$m_3n_1g_3$	3.08	2.64	68.00	74.43	7.14	7.45
$m_3n_2g_1$	3.06	2.68	68.84	71.79	7.18	7.49
$m_3n_2g_2$	2.98	2.60	66.21	69.55	6.95	7.25
$m_3n_2g_3$	2.90	2.65	64.68	67.94	6.79	7.09
$m_4n_1g_1$	2.93	3.00	69.40	76.40	7.39	7.60
$m_4n_1g_2$	3.08	2.97	66.38	75.22	6.97	7.27
$m_4n_1g_3$	3.11	2.98	64.24	71.96	6.75	7.04
$m_4n_2g_1$	3.08	2.94	63.51	67.17	6.67	6.96
$m_4n_2g_2$	2.98	2.90	63.33	63.89	6.39	6.67
$m_4n_2g_3$	3.06	2.91	63.87	62.59	6.30	6.45
$m_5n_1g_1$	2.98	2.91	72.73	76.40	7.76	7.97
$m_5n_1g_2$	3.16	2.93	66.79	74.16	7.02	7.32
$m_5n_1g_3$	3.13	2.86	66.44	72.79	6.98	7.28
$m_5n_2g_1$	3.08	2.85	66.67	70.03	7.00	7.31
$m_5n_2g_2$	3.06	2.77	63.77	68.99	6.80	6.99
$m_5n_2g_3$	2.88	2.84	62.81	66.98	6.49	6.36
SEm (±)	0.11	0.12	2.28	2.11	0.21	0.25
CD (0.05)	NS	NS	NS	NS	NS	NS

Table 22a. Effect of method of planting and nutrient management x growth promoter on NPK uptake, kg ha^{-1}

Treatments	Nutrient uptake					
	2019-20			2020-21		
	N	P	K	N	P	K
Method of planting						
m_1 - Bed method (30 cm x 15 cm)	76.39	25.97	148.17	82.48	25.89	173.96
m_2 - Bed method (30 cm x 30 cm)	50.43	17.26	97.97	55.51	24.67	117.07
m_3 - Ridge method (30 cm x 15 cm)	70.37	24.32	136.55	79.17	25.32	166.99
m_4 - Ridge method (30 cm x 30 cm)	46.79	16.12	92.53	52.83	23.46	111.43
m_5 - Mound method (30 cm x 30 cm)	46.32	16.14	91.87	51.91	23.39	109.48
SEm (±)	0.74	0.32	1.07	1.01	0.28	0.76
CD (0.05)	2.288	0.991	3.283	3.104	0.850	2.326
Nutrient management x growth promoter						
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	64.37	22.10	124.86	70.76	27.04	149.24
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	61.40	20.96	119.19	67.17	25.72	141.66
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Water spray	57.82	19.83	112.54	65.29	24.69	137.70
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	56.80	19.48	111.48	63.45	24.12	133.82
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	55.18	19.15	108.86	61.04	23.45	128.74
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	52.78	18.26	103.58	58.58	22.26	123.56
SEm (±)	0.83	0.25	1.42	0.91	0.34	1.01
CD (0.05)	2.329	0.696	3.998	2.565	0.963	2.842

Table 22b. Interaction effect of method of planting and combination of nutrient management + growth promoter on NPK uptake, kg ha^{-1}

Treatments	Nutrient uptake					
	2019-20			2020-21		
	N	P	K	N	P	K
$m_1n_1g_1$	87.76	29.95	170.49	89.54	29.75	188.85
$m_1n_1g_2$	80.68	27.44	156.25	86.59	27.11	182.64
$m_1n_1g_3$	75.69	25.58	147.06	83.50	26.10	176.12
$m_1n_2g_1$	73.89	25.21	143.54	82.49	25.29	173.99
$m_1n_2g_2$	71.33	24.34	138.57	78.71	24.56	166.00
$m_1n_2g_3$	69.01	23.32	133.09	74.04	22.54	156.15
$m_2n_1g_1$	56.86	19.49	110.46	63.69	27.06	134.34
$m_2n_1g_2$	53.43	18.23	103.79	58.59	25.39	123.58
$m_2n_1g_3$	50.17	17.12	97.46	56.20	24.59	118.53
$m_2n_2g_1$	50.19	17.13	97.51	53.51	24.30	112.86
$m_2n_2g_2$	47.85	16.33	92.97	51.62	23.62	108.87
$m_2n_2g_3$	44.06	15.29	85.61	49.42	23.06	104.24
$m_3n_1g_1$	73.68	25.47	142.18	82.53	27.80	174.06
$m_3n_1g_2$	73.41	25.05	142.61	80.43	26.32	169.63
$m_3n_1g_3$	67.19	23.69	130.54	79.42	25.48	167.50
$m_3n_2g_1$	70.09	23.92	136.17	79.82	24.85	168.34
$m_3n_2g_2$	71.39	24.36	138.70	77.33	24.13	163.09
$m_3n_2g_3$	66.47	23.45	129.13	75.53	23.34	159.31
$m_4n_1g_1$	52.47	18.15	101.93	59.74	25.85	126.00
$m_4n_1g_2$	49.54	17.04	96.25	56.20	25.36	118.53
$m_4n_1g_3$	47.57	16.23	92.42	53.71	23.66	113.28
$m_4n_2g_1$	44.97	15.35	90.71	50.19	23.09	105.86
$m_4n_2g_2$	43.15	15.25	88.24	49.72	22.54	104.87
$m_4n_2g_3$	43.02	14.68	85.62	47.43	20.30	100.04
$m_5n_1g_1$	51.09	17.43	99.25	58.29	24.75	122.95
$m_5n_1g_2$	49.94	17.04	97.03	54.02	24.40	113.93
$m_5n_1g_3$	48.49	16.55	95.22	53.61	23.66	113.07
$m_5n_2g_1$	44.84	15.80	89.46	51.22	23.09	108.03
$m_5n_2g_2$	42.20	15.46	85.82	47.83	22.41	100.88
$m_5n_2g_3$	41.35	14.56	84.44	46.49	22.06	98.04
SEm (±)	1.84	0.60	3.09	2.11	0.75	2.19
CD (0.05)	NS	NS	8.941	NS	NS	6.355

Table 23a. Effect of method of planting and nutrient management x growth promoter on soil pH and organic carbon

Treatments	Soil pH		Organic carbon (%)	
	2019-20	2020-2021	2019-20	2020-2021
Method of planting				
m_1 - Bed method (30 cm x 15 cm)	6.11	6.16	1.12	1.21
m_2 - Bed method (30 cm x 30 cm)	6.11	6.18	1.13	1.18
m_3 - Ridge method (30 cm x 15 cm)	6.12	6.19	1.14	1.18
m_4 - Ridge method (30 cm x 30 cm)	6.12	6.18	1.14	1.18
m_5 - Mound method (30 cm x 30 cm)	6.11	6.19	1.13	1.19
SEm (±)	0.09	0.07	0.01	0.02
CD (0.05)	NS	NS	NS	NS
Nutrient management x growth promoter				
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	6.15	6.23	1.13	1.18
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	6.14	6.23	1.14	1.21
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1+ Water spray	6.12	6.20	1.15	1.21
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	6.08	6.12	1.13	1.19
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	6.08	6.16	1.13	1.18
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	6.10	6.14	1.12	1.18
SEm (±)	0.07	0.07	0.01	0.02
CD (0.05)	NS	NS	NS	NS

Table 23b. Interaction effect of method of planting and combination of nutrient management + growth promoter on soil pH and organic carbon

Treatments	Soil pH		Organic carbon (%)	
	2019-20		2020-21	
$m_1n_1g_1$	6.18	6.26	1.13	1.24
$m_1n_1g_2$	6.12	6.21	1.11	1.22
$m_1n_1g_3$	6.12	6.19	1.13	1.18
$m_1n_2g_1$	6.10	6.12	1.10	1.19
$m_1n_2g_2$	6.06	6.13	1.14	1.20
$m_1n_2g_3$	6.07	6.07	1.15	1.25
$m_2n_1g_1$	6.14	6.18	1.12	1.19
$m_2n_1g_2$	6.16	6.24	1.15	1.18
$m_2n_1g_3$	6.12	6.20	1.16	1.22
$m_2n_2g_1$	6.08	6.12	1.12	1.17
$m_2n_2g_2$	6.07	6.16	1.12	1.19
$m_2n_2g_3$	6.09	6.16	1.14	1.17
$m_3n_1g_1$	6.14	6.23	1.16	1.22
$m_3n_1g_2$	6.17	6.25	1.12	1.17
$m_3n_1g_3$	6.10	6.17	1.15	1.20
$m_3n_2g_1$	6.06	6.13	1.13	1.19
$m_3n_2g_2$	6.11	6.19	1.14	1.16
$m_3n_2g_3$	6.12	6.18	1.12	1.17
$m_4n_1g_1$	6.14	6.22	1.11	1.13
$m_4n_1g_2$	6.15	6.23	1.18	1.23
$m_4n_1g_3$	6.13	6.21	1.14	1.21
$m_4n_2g_1$	6.07	6.11	1.15	1.20
$m_4n_2g_2$	6.09	6.13	1.12	1.16
$m_4n_2g_3$	6.13	6.17	1.13	1.19
$m_5n_1g_1$	6.17	6.25	1.12	1.16
$m_5n_1g_2$	6.11	6.22	1.14	1.23
$m_5n_1g_3$	6.15	6.23	1.15	1.22
$m_5n_2g_1$	6.10	6.14	1.16	1.20
$m_5n_2g_2$	6.08	6.17	1.15	1.19
$m_5n_2g_3$	6.07	6.12	1.09	1.15
SEm (±)	0.18	0.17	0.03	0.04
CD (0.05)	NS	NS	NS	NS

4.1.6.3 Available NPK

The available NPK status in soil assessed after the experiment in both years (Tables 24a and 24b) revealed significant variations in both the years due to the treatments.

During both the years, the variations in available N status due to the methods of planting revealed the highest status (319.35 kg ha^{-1} and 322.27 kg ha^{-1} respectively) in the mound method of planting at 30 cm x 30 cm (m_5) spacing. The values were on par with m_4 and m_2 (318.10 and 317.37 kg ha^{-1} in first year and 321.24 and 320.08 kg ha^{-1} in second year respectively). Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid recorded the highest available N in both the years and were on par with n_1g_2 and n_1g_3. The interaction effects were found to be non significant in both of the years.

The available P in soil was the highest in mound method of planting (m_5) and comparable with that in m_2 and m_4. Among the sub plot treatments, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1+ water spray recorded the highest P status on par with n_1g_1 and n_1g_2 in both years. Exploring the interaction effects, the significantly highest P status was observed in the treatment combination involving m_5 *i.e.* $m_5n_1g_1$ (44.25 kg ha^{-1}) in the first year and $m_5n_1g_1$ (55.11 kg ha^{-1}) in the second year, was on par with $m_5n_1g_3$ (52.12 kg ha^{-1}).

There was significant variation in K status due to methods of planting and combination of nutrient management and growth promoter in both years. Soil K was assessed the highest in mound method of planting (m_5) and on par with m_2 and m_4 in the two years. Comparing the sub plot effects, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1+ water spray recorded the highest K status and was on par with n_1g_1 and n_1g_2 in both years. The interaction effects of methods of planting and combination of nutrient management + growth promoter were significant on available K status in both years. In the first year, higher K was noted in the treatment combination $m_4n_1g_3$ (447.40 kg ha^{-1}) and on par with $m_4n_1g_1$, $m_4n_1g_2$, $m_4n_2g_3$, $m_2n_1g_2$, $m_2n_2g_2$, $m_5n_1g_1$, $m_5n_1g_2$ and $m_5n_1g_3$. In the second year, $m_5n_1g_3$ exhibited a higher K status (452.19 kg ha^{-1}) that was on par with $m_5n_1g_2$, $m_5n_1g_1$, $m_4n_2g_3$, $m_4n_1g_1$, $m_4n_1g_2$, $m_4n_1g_3$ and $m_2n_2g_2$.

4.1.6.4 Microbial Count

Perusal of the data in Tables 25a and 25b revealed that the soil microbial count, bacteria, fungi and actinomycetes, were significantly influenced by the various treatments.

Bacterial population enumerated was higher in the bed method of planting at 30 cm x 15 cm spacing (m_1) and was on par with ridge method with 30 cm x 15 cm spacing (m_3) in both the years and the lowest count was recorded in mound method of planting at 30 cm x 30 cm spacing (m_5) during both the years.

Fungal and actinomycete counts were maximum in m_1 during the first year and the highest fungal count recorded was 13.08 x 10^4 cfu g^{-1} soil. In the second year, the counts in m_1 and m_3 were on par in the case of fungal count. The maximum count of actinomycetes recorded was 6.02 x 10^5 cfu g^{-1} soil and 7.63 x 10^5 cfu g^{-1} soil in first and second year respectively. Ridge method with 30 cm x 30 cm spacing (m_4) recorded the lowest fungal and actinomycete counts.

Among the sub plot treatments, bacterial population was higher for the treatment n_1g_3 (16.95 x 10^6 cfu g^{-1} soil), and was on par with n_1g_1 and n_1g_2 in the first year. In the second year, n_1g_2 showed a higher bacterial population (18.35 x 10^6 cfu g^{-1} soil), but on par with n_1g_1 and n_1g_3. Significantly higher fungal population was enumerated in n_1g_2 during first year (12.85 x 10^4 cfu g^{-1} soil) and n_1g_3 during second year (15.10 x 10^4 cfu g^{-1} soil). The population of actinomycetes was the highest in the subplot treatment n_1g_2, in both of the years (5.15 x 10^5 cfu g^{-1} soil and 6.45 x 10^5 cfu g^{-1} soil) and was on par with n_1g_1 and n_1g_3.

The interaction effect of method of planting x nutrient management + growth promoter combination, showed a significantly higher bacterial count in the

Table 24a. Effect of method of planting and nutrient management x growth promoter on available NPK status in soil, kg ha^{-1}

Treatments	2019-20			2020-21		
	Available N	Available P	Available K	Available N	Available P	Available K
Method of planting						
m_1 - Bed method (30 cm x 15 cm)	309.73	29.91	374.28	312.65	37.46	383.02
m_2 - Bed method (30 cm x 30 cm)	317.37	35.13	408.89	320.08	44.80	418.44
m_3 - Ridge method (30 cm x 15 cm)	310.99	31.60	376.84	314.12	38.48	385.64
m_4 - Ridge method (30 cm x 30 cm)	318.10	36.00	422.26	321.24	44.84	432.12
m_5 - Mound method (30 cm x 30 cm)	319.35	36.90	423.49	322.27	45.96	433.38
SEm (±)	1.93	0.60	4.86	1.86	0.42	5.46
CD (0.05)	5.935	1.850	14.986	5.728	1.296	16.837
Nutrient management x growth promoter						
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	322.39	38.14	413.47	325.02	47.15	423.13
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	319.37	37.06	409.24	322.25	46.36	418.80
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1+ Water spray	319.74	38.15	414.18	322.88	47.21	423.85
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	310.09	30.19	388.50	312.97	37.80	397.57
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	308.58	29.70	387.80	311.72	37.48	396.85
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	310.46	30.22	393.72	313.60	37.83	402.92
SEm (±)	3.08	0.46	5.04	2.63	0.48	5.13
CD (0.05)	8.681	1.284	14.189	7.415	1.350	14.446

Table 24b. Interaction effect of method of planting and combination of nutrient management + growth promoter on soil available NPK status, kg ha^{-1}

Treatments	2019-20			2020-21		
	Available N	Available P	Available K	Available N	Available P	Available K
$m_1n_1g_1$	314.87	31.61	401.13	316.74	40.62	410.50
$m_1n_1g_2$	312.33	32.13	396.74	315.46	40.02	406.01
$m_1n_1g_3$	309.19	31.77	403.03	312.33	39.57	412.44
$m_1n_2g_1$	307.33	27.86	349.93	310.46	34.70	358.10
$m_1n_2g_2$	304.19	27.33	342.38	307.33	34.04	350.38
$m_1n_2g_3$	310.47	28.74	352.47	313.60	35.79	360.70
$m_2n_1g_1$	324.28	39.66	410.20	326.14	49.39	419.78
$m_2n_1g_2$	321.14	38.20	398.41	323.01	49.33	407.72
$m_2n_1g_3$	324.28	40.69	404.40	327.42	50.67	413.85
$m_2n_2g_1$	313.60	30.23	409.17	316.74	38.65	418.73
$m_2n_2g_2$	313.60	30.40	425.14	316.74	40.36	435.07
$m_2n_2g_3$	307.33	31.63	406.02	310.46	40.39	415.50
$m_3n_1g_1$	313.60	34.64	383.10	316.74	40.14	392.05
$m_3n_1g_2$	310.46	34.14	380.36	313.60	41.77	389.24
$m_3n_1g_3$	313.60	35.90	374.19	316.74	43.21	382.93
$m_3n_2g_1$	310.46	28.87	371.53	313.60	35.96	380.21
$m_3n_2g_2$	307.33	28.74	366.04	310.46	35.79	374.59
$m_3n_2g_3$	310.46	27.33	385.81	313.60	34.04	394.82
$m_4n_1g_1$	329.92	40.54	432.78	333.05	50.49	442.89
$m_4n_1g_2$	326.78	40.04	434.04	329.92	49.87	444.18
$m_4n_1g_3$	333.05	40.53	447.40	336.19	50.48	457.85
$m_4n_2g_1$	307.33	32.13	401.76	310.47	40.02	411.14
$m_4n_2g_2$	304.19	31.00	399.34	307.33	38.61	408.67
$m_4n_2g_3$	307.33	31.76	418.23	310.46	39.55	428.00
$m_5n_1g_1$	329.28	44.25	440.16	332.42	55.11	450.44
$m_5n_1g_2$	326.14	40.80	436.66	329.28	50.81	446.86
$m_5n_1g_3$	318.60	41.85	441.87	321.74	52.12	452.19
$m_5n_2g_1$	311.74	31.88	410.09	313.60	39.70	419.67
$m_5n_2g_2$	313.60	31.00	406.08	316.74	38.61	415.56
$m_5n_2g_3$	316.74	31.63	406.08	319.87	39.39	415.56
SEm (±)	6.89	1.02	11.26	5.69	1.06	11.81
CD (0.05)	NS	2.871	31.727	NS	3.018	32.303

Table 25a. Effect of method of planting and nutrient management x growth promoter on microbial count and dehydrogenase activity in soil

Treatments	2019-20				2020-21			
	Bacteria (x10^{6}) cfu g^{-1} soil	Fungi (x10^{4}) cfu g^{-1} soil	Actinomycetes (x10^{5}) cfu g^{-1} soil	Dehydrogenase activity (µg of TPF g^{-1} soil 24h^{-1})	Bacteria (x10^{6}) cfu g^{-1} soil	Fungi (x10^{4}) cfu g^{-1} soil	Actinomycetes (x10^{5}) cfu g^{-1} soil	Dehydrogenase activity (µg of TPF g^{-1} soil 24h^{-1})
Method of planting								
m_1 - Bed method (30 cm x 15 cm)	17.25	13.08	6.92	30.59	19.25	14.79	7.63	32.25
m_2 - Bed method (30 cm x 30 cm)	13.96	9.33	4.17	26.33	15.83	12.08	4.96	26.98
m_3 - Ridge method (30 cm x 15 cm)	17.04	10.46	4.21	29.27	18.83	14.00	6.08	30.88
m_4 - Ridge method (30 cm x 30 cm)	15.75	4.83	3.25	25.09	15.79	10.42	4.71	25.47
m_5 - Mound method (30 cm x 30 cm)	13.92	9.38	4.17	23.94	14.96	12.08	5.21	24.56
SEm (±)	0.21	0.12	0.12	0.27	0.28	0.34	0.23	0.45
CD (0.05)	0.644	0.383	0.365	0.828	0.876	1.038	0.712	1.396
Nutrient management x growth promoter								
n_1g_1 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Humic acid	16.80	12.65	4.95	30.25	18.15	14.80	6.40	31.39
n_1g_2 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + Benzyl adenine	16.75	12.85	5.15	29.23	18.35	15.05	6.45	30.49
n_1g_3 - 60:30:120 kg NPK ha^{-1} + PGPR Mix 1+ Water spray	16.95	12.75	4.90	29.75	18.10	15.10	6.20	30.59
n_2g_1 - 60:30:120 kg NPK ha^{-1} + Humic acid	14.25	6.00	4.05	24.69	15.60	10.50	5.10	25.75
n_2g_2 - 60:30:120 kg NPK ha^{-1} + Benzyl adenine	14.55	6.20	4.15	24.08	15.80	10.30	5.30	24.75
n_2g_3 - 60:30:120 kg NPK ha^{-1} + Water spray	14.20	6.05	4.05	24.28	15.60	10.30	4.85	25.20
SEm (±)	0.18	0.15	0.18	0.34	0.21	0.22	0.23	0.37
CD (0.05)	0.496	0.423	0.521	0.969	0.604	0.633	0.641	1.052

Table 25b. Interaction effect of method of planting and combination of nutrient management + growth promoter on microbial count and dehydrogenase activity in soil

Treatments	2019-20				2020-21			
	Bacteria (x 10^6) cfu g^{-1} soil	Fungi (x10^4) cfu g^{-1} soil	Actinomycetes (x10^5) cfu g^{-1} soil	Dehydrogenase activity (µg of TPF g^{-1} soil $24h^{-1}$)	Bacteria (x10^6) cfu g^{-1} soil	Fungi (x10^4) cfu g^{-1} soil	Actinomycetes (x 10^5) cfu g^{-1} soil	Dehydrogenase activity (µg of TPF g^{-1} soil $24h^{-1}$)
$m_1n_1g_1$	19.25	16.25	6.50	34.69	21.25	18.00	7.25	37.11
$m_1n_1g_2$	19.00	16.25	7.00	35.26	21.50	17.75	7.50	37.62
$m_1n_1g_3$	19.50	16.50	6.75	34.99	21.25	18.25	7.75	37.62
$m_1n_2g_1$	15.25	9.75	7.00	27.00	17.25	11.50	8.00	27.56
$m_1n_2g_2$	15.50	10.00	7.00	25.05	17.25	11.75	7.50	26.05
$m_1n_2g_3$	15.00	9.75	7.25	26.56	17.00	11.50	7.75	27.56
$m_2n_1g_1$	15.50	11.25	5.25	30.34	17.25	14.00	6.00	30.59
$m_2n_1g_2$	15.50	11.50	4.50	29.87	17.50	14.25	5.50	30.59
$m_2n_1g_3$	15.50	11.25	4.50	27.40	17.25	14.00	5.00	28.08
$m_2n_2g_1$	12.25	7.25	3.75	24.67	14.25	10.00	4.50	25.05
$m_2n_2g_2$	12.75	7.50	3.50	21.02	14.50	10.25	4.50	22.54
$m_2n_2g_3$	12.25	7.25	3.50	24.69	14.25	10.00	4.25	25.05
$m_3n_1g_1$	18.50	15.25	4.25	31.54	20.00	16.25	7.00	33.60
$m_3n_1g_2$	18.25	15.50	4.50	31.66	20.25	16.75	7.25	33.60
$m_3n_1g_3$	18.75	15.25	4.25	31.49	20.00	16.50	6.75	31.60
$m_3n_2g_1$	15.50	5.50	4.00	26.83	17.50	11.50	5.25	29.57
$m_3n_2g_2$	16.00	5.75	4.25	26.93	17.75	11.75	5.75	28.08
$m_3n_2g_3$	15.25	5.50	4.00	27.18	17.50	11.25	4.50	28.82
$m_4n_1g_1$	16.25	6.25	3.00	27.68	16.50	10.50	5.25	28.06
$m_4n_1g_2$	16.25	6.50	3.50	24.68	16.50	11.00	5.00	25.56
$m_4n_1g_3$	16.25	6.25	3.25	27.84	16.25	11.25	5.00	28.06
$m_4n_2g_1$	15.25	3.25	3.25	23.45	15.00	11.00	4.50	24.54
$m_4n_2g_2$	15.25	3.50	3.25	25.40	15.25	9.50	4.25	24.54
$m_4n_2g_3$	15.25	3.25	3.25	21.50	15.25	9.25	4.25	22.03
$m_5n_1g_1$	14.50	14.25	5.75	26.99	15.75	15.25	6.50	27.57
$m_5n_1g_2$	14.75	14.50	6.25	24.67	16.00	15.50	7.00	25.06
$m_5n_1g_3$	14.75	14.50	5.75	27.01	15.75	15.50	6.50	27.57
$m_5n_2g_1$	13.00	4.25	2.25	21.49	14.00	8.50	3.25	22.05
$m_5n_2g_2$	13.25	4.25	2.75	22.01	14.25	8.25	4.50	22.54
$m_5n_2g_3$	13.25	4.50	2.25	21.49	14.00	9.50	3.50	22.54
SEm (±)	0.42	0.30	0.41	0.75	0.52	0.57	0.52	0.89
CD (0.05)	1.108	0.945	1.165	2.166	1.350	1.416	1.433	2.353

treatment combination $m_1n_1g_3$ (19. 50 x 10^6 cfu g^{-1} soil), on par with $m_1n_1g_2$, $m_1n_1g_1$, $m_3n_1g_1$ and $m_3n_1g_3$ in the first year. In the second year, $m_1n_1g_2$ recorded the highest bacterial population (21.50 x 10^6 cfu g^{-1} soil) on par with $m_1n_1g_1$, $m_1n_1g_3$ and $m_3n_1g_2$.

Comparing the variations in fungal counts, the count enumerated during both the years was maximum in $m_1n_1g_3$ (16.50 x 10^4 cfu g^{-1} soil and 18.25 x 10^4 cfu g^{-1} soil in first and second year respectively) and was comparable with $m_1n_1g_2$ and $m_1n_1g_1$ in both the years. Actinomycete count was the highest in $m_1n_2g_3$ (7.25 x 10^5 cfu g^{-1} soil) in the first year and on par with $m_1n_1g_1$, $m_1n_1g_2$, $m_1n_1g_3$, $m_2n_1g_1$ $m_1n_2g_2$ and $m_5n_1g_2$. In the second year, $m_1n_2g_1$ showed the maximum population (8.00 x 10^5 cfu g^{-1} soil) on par with $m_1n_1g_1$, $m_1n_1g_2$, $m_1n_1g_3$, $m_1n_2g_2$, $m_1n_2g_3$, $m_3n_1g_1$, $m_3n_1g_2$, $m_3n_1g_3$ and $m_5n_1g_2$.

4.1.6.5 Dehydrogenase Activity

The variation in dehydrogenase activity in response to the different methods of planting and combination of nutrient management and growth promoter are presented in Tables 25a and 25b. In both the years, markedly higher dehydrogenase activity was estimated in m_1 (30.59 µg of TPF g^{-1} soil $24h^{-1}$ and 32.25 µg of TPF g^{-1} soil $24h^{-1}$ respectively), the latter being on par with ridge planting at 30 cm x 15 cm (m_3). The combination of NPK with growth promoter also significantly influenced the dehydrogenase activity in both the years of experimentation. The treatment n_1g_1 recorded superior values of dehydrogenase activity (30.25 µg of TPF g^{-1} soil $24h^{-1}$ and 31.39 µg of TPF g^{-1} soil $24h^{-1}$) in both the years and was on par with n_1g_3 in the first year and with n_1g_2 and n_1g_3 in the second year.

Among the treatment combination $m_1n_1g_2$ recorded the highest value of dehydrogenase activity (35.26 µg of TPF g^{-1} soil $24h^{-1}$) and was on par with $m_1n_1g_1$ and $m_1n_1g_3$ in the first year and the same combinations were on par in the second year with $m_1n_1g_2$ and $m_1n_1g_2$ that recorded the maximum value (37.62 µg of TPF g^{-1} soil $24h^{-1}$).

4.1.7 Pest and Disease Incidence

The pest infestation and disease incidence in Chinese potato were monitored during the entire crop growth. Leaf webber was the only pest noticed in the field at 35 DAP and as control measure, as soon as the infestation was noticed, a spray of Chlorantraniliprole @ 3 mL 10 L^{-1} was given and hence could be managed without affecting yield.

4.1.8 Economic Analysis

The economics of cultivation in response to the management practices adopted are presented in Table 26. The management practice involving a bed method of land preparation, planting at 30 cm x 15 cm spacing and application of NPK @ 60:30:120 kg ha^{-1} + PGPR Mix 1 + humic acid was reckoned as the most profitable in both years of experimentation. The net returns and BCR computed were ₹ 625639 ha^{-1} and 3.72 respectively in the first year and ₹ 676953 ha^{-1} and 3.95 respectively in the second year. Average of the economic analysis of the two years also revealed the same trend, with the maximum mean net returns computed being ₹ 651296 ha^{-1} and BCR, 3.83.

4.2 EXPERIMENT II: INFLUENCE OF CARBON DIOXIDE FERTILIZATION ON GROWTH, YIELD AND TUBER QUALITY IN CHINESE POTATO

4.2.1 Microclimate (At Weekly Interval)

Observations on microclimate *viz*. CO_2 release, air temperature and soil temperature (5 cm depth) were recorded at weekly intervals and are presented in Tables 27a to 29b.

4.2.1.1 CO_2 Release

The daily CO_2 release from each trench monitored at weekly interval and the data are depicted in Tables 27a and 27b. In the first year, excessive vegetative growth and delay in tuber initiation was noticed and hence the crop was

Table 26. Effect of method of planting and combination of nutrient management + growth promoter on economics of cultivation*

Treatments	Net returns (₹/ha)			BCR		
	2019-20	2020-21	Mean	2019-20	2020-21	Mean
$m_1n_1g_1$	625639	676953	651296	3.72	3.95	3.83
$m_1n_1g_2$	510556	569200	539878	2.88	3.10	2.99
$m_1n_1g_3$	509880	562093	535986	3.23	3.46	3.35
$m_1n_2g_1$	499067	558939	529003	3.29	3.56	3.43
$m_1n_2g_2$	436921	484720	460820	2.69	2.87	2.78
$m_1n_2g_3$	448639	487483	468061	3.07	3.25	3.16
$m_2n_1g_1$	509422	550861	530142	3.31	3.50	3.40
$m_2n_1g_2$	448677	458513	453595	2.71	2.75	2.73
$m_2n_1g_3$	431468	470372	450920	2.97	3.15	3.06
$m_2n_2g_1$	429209	445140	437174	3.00	3.07	3.04
$m_2n_2g_2$	353791	379648	366719	2.38	2.48	2.43
$m_2n_2g_3$	372693	399242	385968	2.75	2.87	2.81
$m_3n_1g_1$	548418	584688	566553	3.36	3.51	3.43
$m_3n_1g_2$	453045	493492	473268	2.65	2.80	2.73
$m_3n_1g_3$	469171	509459	489315	3.03	3.20	3.12
$m_3n_2g_1$	448619	513312	480966	3.03	3.32	3.18
$m_3n_2g_2$	384961	435586	410274	2.47	2.66	2.57
$m_3n_2g_3$	356824	454308	405566	2.63	3.07	2.85
$m_4n_1g_1$	488888	494286	491587	3.19	3.21	3.20
$m_4n_1g_2$	413980	420872	417426	2.56	2.59	2.58
$m_4n_1g_3$	438313	450382	444348	2.97	3.03	3.00
$m_4n_2g_1$	420686	423220	421953	2.93	2.94	2.94
$m_4n_2g_2$	356485	350095	353290	2.38	2.35	2.36
$m_4n_2g_3$	381904	364145	373025	2.77	2.69	2.73
$m_5n_1g_1$	439788	422292	431040	2.94	2.86	2.90
$m_5n_1g_2$	360574	356942	358758	2.35	2.33	2.34
$m_5n_1g_3$	382040	386752	384396	2.70	2.72	2.71
$m_5n_2g_1$	360876	363098	361987	2.64	2.65	2.64
$m_5n_2g_2$	298216	295928	297072	2.14	2.13	2.13
$m_5n_2g_3$	314363	317700	316031	2.43	2.45	2.44

* Data statistically not analysed

maintained until 238 days in the first year and for 146 days in the second year. The CO_2 release measurements were taken until 27 weeks in the first year and for 19 weeks in the second year.

The CO_2 concentration in $s_{0,}$ where no substrate was provided, did not show much variation and values were almost constant, 445 to 455 ppm during the cropping period in the first year and 445 to 457 ppm during second year.

The treatments in which substrates were added evinced maximum CO_2 release during the first week of application irrespective of the substrate used thereafter it declined. The highest peak of CO_2 concentration was observed in s_5 (cow dung + coir pith + *Pleurotus* + N + P), 858 and 842 ppm followed by s_3 [cow dung + coir pith (2:1)], 752 and 722 ppm, during both the years, where the substrate used was cow dung + coir pith + *Pleurotus* + N + P in the former. The percentage increase recorded within a week were 26.2 and 22.7 per cent and during first year and 25.7 and 19.9 per cent during the second year respectively. Thereafter a decline was noticed and the values remained comparatively higher in s_5 during both the years. During the last observation, the CO_2 concentration were in a range of 444 ppm in s_0 to 462 ppm in s_5 in the first year and 446 ppm in s_0 to 501 ppm in s_5 during the second year.

4.2.1.2 Air Temperature

The daily air temperature recorded at weekly interval in all the treatments compared to ambient temperature recorded at the meteorological observatory is given in Tables 28a and 28b.

Air temperature was comparatively lower in s_0 and higher in s_5 during both the years of experimentation. Higher values were recorded in trench containing substrates cow dung + coir pith + *Pleurotus* + N + P followed by s_3. Compared to the ambient temperature, the air temperature in the trenches were higher. A maximum increase of 4.5°C compared to ambient was observed in s_5 at 11th week in first experimental period, and 3.0°C increase in the second experimental period at the same period of observation.

4.2.1.3 Soil Temperature

The data on soil temperature at 5 cm depth recorded at weekly intervals in different treatments are presented in Tables 29a and b.

In general, the soil temperature was found to increase as the growth advanced and maximum temperatures were observed in s_5 and lower in s_0 throughout the growth period in both the years. In both the years of experimentation, soil temperature observed in the trenches were comparatively higher during the vegetative growth stages and tuber initiation (50-55 DAP). A maximum increase of 3.5°C soil temperature was observed in s_5 during second week in the first year and a difference of 0.9 to 2.9°C was observed in s_5 during the second year compared to the open. The maximum temperature recorded was 28°C in s_5 during the second week of first experimental period whereas the temperature recorded in s_0 was 27.5°C during this period.

4.2.2 Growth Attributes

Growth attributes *viz.*, plant height, number of branches per plant, number of leaves per plant and leaf area at 30 days interval were recorded and are presented in Tables 30 to 33. Significantly higher growth attributes were recorded in plants exposed to CO_2 fertilization compared to plants with no substrate application.

4.2.2.1 Plant Height

The effect of CO_2 fertilization on plant height at 30 days interval is given in Table 30. There was significant variation in plant height with the treatments at all the growth stages, except at 120 DAP during both the years of study (Table 30).

At 30 DAP in the first year, significantly taller plants (19.98 cm) were observed in the treatment in which cow dung + coir pith (2:1) was used as substrate (s_3), but on par with coir pith + *Pleurotus* + N + P (s_4) and cow dung + coir pith (2:1) + *Pleurotus* + N + P (s_5), the values being 18.58 and 18.83 cm respectively. During the second year, the maximum plant height (19.70 cm) was noted in s_3 on par with s_4, s_5 and s_1.

The superiority of substrate containing cow dung + coir pith (2:1) + *Pleurotus* + N + P (s_5) on plant height in the trench was evident at 60 and 90 DAP during both the years. The height of plants in treatment s_5 was on par with s_4 during the first year and s_3 and s_4 during the second year at 60 DAP whereas at 90 DAP, it was on par with s_4. Plants were the shortest in trenches with no substrate application (s_0). At 120 DAP, the plant height remained comparable in all treatments in both years.

4.2.2.2 Number of Branches per Plant

The data on number of branches per plant as influenced by eCO_2 concentration are presented in Table 31. Perusal of data revealed the significant influence on number of branches at all stages of observation.

At 30 DAP, the plants grown in the treatment s_3 produced more branches per plant (13.2 and 12.8 during the first and second year respectively) and were on par with s_5 (12.0 and 11.7). The significantly highest branch number was recorded in the trench spread with cow dung + coir pith (2:1) + *Pleurotus* + N + P (s_5) during both the years at 60 DAP (18.0 and 17.2 cm), 90 DAP (36.7 and 34.7 cm) and 120 DAP (37.0 and 30.5 cm) and was comparable with s_3.

4.2.2.3 Number of Leaves per Plant

The effect of CO_2 fertilization on the number of leaves per plant is given in Table 32. Significant differences in the number of leaves per plant were observed at all stages of growth during both years. The number of leaves per plant

Table 27a. Variations in CO_2 release from the different substrates at weekly intervals during 2019-20, ppm

Date of observation	s_0	s_1	s_2	s_3	s_4	s_5
Initial	445					
08.11.2019	446	584	485	616	505	680
15.11.2019	447	640	502	752	606	858
22.11.2019	451	621	500	740	599	831
29.11.2019	455	609	496	739	590	820
06.12.2019	450	600	491	723	585	789
13.12.2019	448	587	490	702	577	750
20.12.2019	447	579	489	696	570	730
27.12.2019	452	565	485	689	570	729
03.01.2020	452	559	485	680	568	716
10.01.2020	453	553	484	676	563	703
17.01.2020	451	531	483	671	560	679
24.01.2020	447	525	483	650	560	658
31.01.2020	448	520	482	643	551	650
07.02.2020	452	518	481	630	540	614
14.02.2020	449	516	480	618	536	601
21.02.2020	454	512	480	603	530	580
28.02.2020	452	507	478	580	529	560
06.03.2020	455	500	478	565	507	544
13.03.2020	450	495	476	524	499	520
20.03.2020	449	470	475	501	486	499
27.03.2020	453	470	475	489	480	481
03.04.2020	452	469	474	487	471	480
10.04.2020	449	468	470	478	470	467
17.04.2020	448	467	460	473	465	466
24.04.2020	453	467	465	470	464	465
01.05.2020	445	464	453	465	463	464
08.05.2020	444	460	450	462	461	462

Table 27b. Variations in CO_2 release from the different substrates at weekly intervals, during 2020-21, ppm

Date of observation	s_0	s_1	s_2	s_3	s_4	s_5
Initial	430					
09.10.2020	445	557	483	602	530	670
16.10.2020	452	679	501	722	597	842
23.10.2020	451	653	493	695	590	801
30.10.2020	455	610	493	680	576	784
06.11.2020	457	588	492	674	568	775
13.11.2020	456	574	490	663	561	763
20.11.2020	454	563	487	654	549	720
27.11.2020	456	558	487	639	543	709
04.12.2020	451	542	480	621	540	688
11.12.2020	452	537	477	610	540	674
18.12.2020	450	526	477	589	539	670
25.12.2020	453	518	475	578	520	659
01.01.2021	454	511	474	565	510	648
08.01.2021	449	502	474	560	509	620
15.01.2021	446	498	470	530	509	603
22.01.2021	448	498	470	521	501	570
29.01.2021	447	487	468	510	500	549
05.02.2021	449	484	465	498	493	525
12.02.2021	446	476	465	490	481	501

Table 28a. Effect of CO_2 fertilization on air temperature during 2019-20, °C

Date of observation	s_0	s_1	s_2	s_3	s_4	s_5	Ambient
08.11.2019	26.5	26.8	26.7	26.9	26.9	27.1	26.8
15.11.2019	26.5	27.2	27.1	27.3	27.4	27.4	26.6
22.11.2019	26.6	27.0	27.0	27.1	27.1	27.2	25.2
29.11.2019	26.5	27.1	27.0	27.2	27.2	27.3	26.6
06.12.2019	26.5	26.9	26.8	27.0	26.9	27.1	25.8
13.12.2019	26.3	26.7	26.7	26.9	26.9	27.1	25.6
20.12.2019	26.4	26.6	26.6	26.9	27.0	27.0	25.2
27.12.2019	26.5	26.8	26.7	27.0	27.0	27.1	25.8
03.01.2020	26.7	26.9	26.8	27.1	26.9	27.2	25.4
10.01.2020	26.6	26.8	26.7	27.0	26.9	27.1	23.8
17.01.2020	26.8	27.1	27.0	27.2	27.1	27.3	22.8
24.01.2020	26.7	27.2	27.3	27.7	27.6	27.9	25.8
31.01.2020	27.0	27.8	27.5	27.8	27.8	27.9	23.8
07.02.2020	27.1	27.2	27.3	27.5	27.8	27.9	24.6
14.02.2020	27.9	28.0	27.9	28.1	28.0	28.3	27.2
21.02.2020	27.4	27.6	27.5	27.6	27.5	27.6	25.4
28.02.2020	27.5	27.6	27.7	27.8	27.7	27.9	25.4
06.03.2020	28.6	28.5	28.3	28.4	28.3	28.4	25.4
13.03.2020	28.5	28.4	28.4	28.6	28.6	28.7	26.8
20.03.2020	28.4	28.5	28.5	28.6	28.7	28.8	26.6
27.03.2020	28.6	28.7	28.7	28.9	28.8	29.0	27.4
03.04.2020	29.1	29.3	29.3	30.3	30.2	30.4	27.8
10.04.2020	28.8	29.0	29.1	29.1	29.0	29.1	27.2
17.04.2020	30.2	30.4	30.3	30.5	30.4	30.6	28.2
24.04.2020	29.7	30.3	30.2	30.1	30.2	29.8	27.4
01.05.2020	29.6	29.9	29.8	30.1	30.0	30.2	28.4
08.05.2020	29.8	30.0	29.8	29.9	29.8	30.1	26.8

Table 28b. Effect of CO_2 fertilization on air temperature during 2020-21, °C

Date of observation	s_0	s_1	s_2	s_3	s_4	s_5	Ambient
09.10.2020	26.3	26.4	26.9	27.1	26.9	27.3	22.2
16.10.2020	26.4	26.7	26.5	27.6	27.9	28.1	26.8
23.10.2020	26.6	27.2	26.8	27.5	27.4	27.9	26.8
30.10.2020	26.5	26.9	26.7	27.4	27.3	27.8	27.0
06.11.2020	26.5	26.8	26.7	26.9	27.2	27.9	27.4
13.11.2020	26.5	27.1	26.9	27.5	27.2	27.6	25.6
20.11.2020	27.0	27.3	27.3	27.7	27.5	27.9	26.6
27.11.2020	27.0	27.3	27.4	27.7	27.6	27.9	25.6
04.12.2020	27.1	27.3	27.5	27.7	27.6	27.8	25.6
11.12.2020	27.1	27.4	27.6	27.2	27.2	27.5	26.4
18.12.2020	27.2	27.4	27.5	27.5	27.3	27.6	24.6
25.12.2020	27.0	27.2	27.1	27.3	27.4	27.5	25.2
01.01.2021	26.8	27.1	27.0	27.2	27.1	27.3	24.8
08.01.2021	26.7	27.2	27.1	27.3	27.2	27.5	26.8
15.01.2021	26.9	27.3	27.1	27.4	27.3	27.6	25.4
22.01.2021	27.0	27.3	27.2	27.4	27.2	27.5	26.2
29.01.2021	26.9	27.2	27.3	27.5	27.4	27.7	23.2
05.02.2021	27.2	27.4	27.2	27.6	27.4	27.6	24.4
12.02.2021	27.3	27.5	27.4	27.7	27.5	27.8	22.6

Table 29a. Effect of CO_2 fertilization on soil temperature during 2019-20, °C

Date of observation	s_0	s_1	s_2	s_3	s_4	s_5	Open
08.11.2019	27.4	27.6	27.5	27.8	27.6	27.9	25.4
15.11.2019	27.5	27.7	27.5	27.5	27.9	28.0	24.5
22.11.2019	27.5	27.6	27.4	27.5	27.7	27.8	25.4
29.11.2019	27.6	27.7	27.6	27.9	28.0	28.2	25.0
06.12.2019	27.5	27.7	27.6	27.8	27.9	28.1	25.2
13.12.2019	27.4	27.8	27.6	27.9	27.7	27.9	25.3
20.12.2019	27.5	27.7	27.7	28.1	28.0	28.1	25.3
27.12.2019	27.6	27.8	27.7	27.8	27.8	27.9	25.7
03.01.2020	27.7	27.9	27.8	27.9	27.9	27.9	25.5
10.01.2020	27.4	27.9	27.8	27.8	27.9	28.0	25.0
17.01.2020	27.6	28	27.8	27.9	28.0	28.1	25.2
24.01.2020	27.3	27.8	27.7	27.8	27.8	27.9	25.6
31.01.2020	27.9	27.9	27.8	28.1	28.2	28.3	25.6
07.02.2020	27.8	27.9	27.9	28.1	28.3	28.4	25.8
14.02.2020	28.0	28.1	28.0	28.4	28.3	28.5	30.3
21.02.2020	27.9	28.2	28.1	28.5	28.4	28.6	25.8
28.02.2020	28.6	28.5	28.5	28.7	28.7	28.8	31.0
06.03.2020	28.6	28.9	28.5	28.6	28.6	28.6	25.3
13.03.2020	28.7	28.9	28.4	28.6	28.6	28.6	30.8
20.03.2020	28.9	28.7	28.9	28.8	28.9	28.9	32.0
27.03.2020	28.5	28.6	28.5	28.6	28.6	28.7	30.7
03.04.2020	29.2	29.3	29.3	29.4	29.2	29.6	30.4
10.04.2020	28.7	28.8	28.7	28.9	28.8	29.0	30.2
17.04.2020	29.8	29.9	29.8	30.0	29.9	30.2	30.6
24.04.2020	29.5	29.7	29.7	29.8	29.7	29.9	30.2
01.05.2020	29.6	29.6	29.6	29.7	29.6	29.7	30.2
08.05.2020	29.5	29.6	29.7	29.8	29.8	29.9	28.2

Table 29b. Effect of CO_2 fertilization on soil temperature during 2020-21, °C

Date of observation	s_0	s_1	s_2	s_3	s_4	s_5	Open
09.10.2020	27.0	27.1	27.1	27.1	27.1	27.3	25.2
16.10.2020	27.5	27.8	27.9	27.8	27.9	27.9	25.9
23.10.2020	27.6	27.9	27.8	27.9	27.9	28.0	26.5
30.10.2020	27.9	27.5	27.1	27.6	27.8	27.7	26.8
06.11.2020	27.5	27.4	27.3	27.6	27.7	27.8	26.4
13.11.2020	26.9	26.9	27.1	27.0	27.2	27.1	25.8
20.11.2020	27.0	26.9	27.3	27.1	27.2	27.3	25.9
27.11.2020	26.9	27.1	27.0	27.3	27.1	27.2	25.8
04.12.2020	26.8	27.4	27.5	26.7	27.5	27.4	26.0
11.12.2020	26.8	27.3	27.0	27.5	27.3	27.4	25.8
18.12.2020	26.3	26.2	26.3	26.1	26.6	26.6	25.2
25.12.2020	27.9	28.0	27.7	27.8	27.7	27.9	27.4
01.01.2021	27.6	27.6	27.8	27.7	27.8	27.8	26.2
08.01.2021	28.0	27.9	28.1	28.0	28.2	28.1	27.4
15.01.2021	28.1	28.0	28.2	28.1	27.9	28.3	25.8
22.01.2021	27.7	27.8	28.0	28.1	28.0	28.1	27.6
29.01.2021	27.8	28.0	27.9	28.1	28.3	28.4	25.8
05.02.2021	28.0	28.1	28.0	28.2	28.3	28.5	26.8
12.02.2021	28.2	28.0	28.3	28.4	28.3	28.5	25.6

Table 30. Effect of CO_2 fertilization on plant height, cm

Treatments	Plant height							
	2019-20				2020-21			
	30 DAP	60 DAP	90 DAP	120 DAP	30 DAP	60 DAP	90 DAP	120 DAP
s_0: No substrate	15.40	19.54	21.92	23.70	15.17	19.23	21.50	24.70
s_1: Cow dung	18.01	21.72	22.83	24.90	17.73	21.50	22.44	23.53
s_2: Coir pith	17.47	21.98	22.65	24.56	17.23	21.77	22.18	23.00
s_3: Cow dung + Coir pith (2:1)	19.98	22.29	24.31	25.51	19.70	22.00	23.83	24.20
s_4: s_2 + *Pleurotus* + N + P	18.58	22.63	25.29	25.79	18.00	22.37	24.17	24.40
s_5: s_3 + *Pleurotus* + N + P	18.83	23.65	26.98	27.96	18.67	23.27	26.30	26.53
SEm (±)	0.50	0.37	0.59	0.71	0.65	0.43	0.73	0.60
CD (0.05)	1.530	1.125	1.821	NS	1.994	1.334	2.249	NS

Table 31. Effect of CO_2 fertilization on number of branches per plant

Treatments	Number of branches per plant							
	2019-20				2020-21			
	30 DAP	60 DAP	90 DAP	120 DAP	30 DAP	60 DAP	90 DAP	120 DAP
s_0: No substrate	9.2	15.2	19.2	19.8	9.0	14.0	17.7	16.3
s_1: Cow dung	11.5	16.0	29.5	29.8	11.2	14.7	28.2	25.8
s_2: Coir pith	11.3	15.5	27.8	28.8	10.8	14.4	26.8	24.8
s_3: Cow dung + Coir pith (2:1)	13.2	16.8	32.8	33.2	12.8	14.3	32.2	29.0
s_4: s_2 + *Pleurotus* + N + P	11.2	17.0	29.8	30.5	11.0	15.3	25.3	23.0
s_5: s_3 + *Pleurotus* + N + P	12.0	18.0	36.7	37.0	11.7	17.2	34.7	30.5
SEm (±)	0.4	0.2	0.7	0.8	0.4	0.4	0.9	0.9
CD (0.05)	1.38	0.68	2.05	2.42	1.16	1.33	2.73	2.69

Table 32. Effect of CO_2 fertilization on number of leaves per plant

Treatments	Number of leaves per plant							
	2019-20				2020-21			
	30 DAP	60 DAP	90 DAP	120 DAP	30 DAP	60 DAP	90 DAP	120 DAP
s_0: No substrate	58.0	79.3	83.5	86.7	50.0	69.3	76.8	71.8
s_1: Cow dung	67.5	98.2	108.8	116.2	61.7	89.8	99.0	83.5
s_2: Coir pith	64.7	86.7	107.2	113.5	57.3	80.0	97.0	83.7
s_3: Cow dung + Coir pith (2:1)	72.7	108.3	121.3	127.5	64.0	100.0	114.7	95.8
s_4: s_2 + *Pleurotus* 1g kg^{-1} + N + P	68.5	100.3	120.5	126.5	59.3	94.3	112.2	95.0
s_5: s_3 + *Pleurotus* 1g kg^{-1} + N + P	69.8	115.7	126.7	132.8	60.3	108.8	120.7	100.7
SEm (±)	1.5	2.7	2.7	2.8	1.7	2.9	3.1	2.9
CD (0.05)	4.49	8.21	8.37	8.53	5.37	8.89	9.66	9.01

Table 33. Effect of CO_2 fertilization on number of leaf area per plant, cm^2

Treatments	Leaf area per plant							
	2019-20				2020-21			
	30 DAP	60 DAP	90 DAP	120 DAP	30 DAP	60 DAP	90 DAP	120 DAP
s_0: No substrate	749.44	1019.48	1049.95	1104.95	711.11	962.81	1009.95	832.88
s_1: Cow dung	843.28	1243.20	1321.48	1346.48	808.28	1189.87	1251.48	971.93
s_2: Coir pith	932.91	1169.73	1318.95	1334.02	901.25	1109.73	1268.95	977.92
s_3: Cow dung + Coir pith (2:1)	1051.38	1389.84	1467.60	1475.94	1014.04	1329.84	1407.60	1121.28
s_4: s_2 + *Pleurotus* 1g kg^{-1} + N + P	792.03	1213.03	1340.39	1362.05	747.36	1166.36	1302.39	1105.33
s_5: s_3 + *Pleurotus* 1g kg^{-1} + N + P	960.84	1446.84	1499.06	1514.06	928.17	1385.18	1448.06	1184.79
SEm (±)	33.77	34.74	43.21	40.52	29.80	41.36	57.88	38.52
CD (0.05)	104.055	107.051	133.133	124.868	91.825	127.455	178.355	118.695

increased from 30 DAP to 120 DAP during the first year whereas in the second year it showed an increasing trend from 30 DAP to 90 DAP and then decreased.

During the first year, the treatment s_3 produced the maximum number of leaves at 30 DAP (72.7) and it was comparable with s_4 and s_5. As growth advanced the superiority of s_5 was visible throughout wherein it was on par with s_3 at 60 DAP. At later stages of observations *viz.*, 90 and 120 DAP, s_5 was on par with s_3 and s_4.

During the second year also s_3 produced more leaves per plant at 30 DAP (64.0) and was significantly superior to s_2 (57.3). At 60, 90 and 120 DAP, the number of leaves per plant was maximum in s_5 (108.8, 120.7 and 100.7 respectively). The values were comparable with s_3 at all the stages and also with s_4 at 90 and 120 DAP.

4.2.2.4 Leaf Area per Plant

The data on leaf area as influenced by CO_2 fertilization at monthly interval given in Table 33 revealed the significantly higher leaf area at 30 DAP during both the years (1051.38 and 1014.04 cm^2) in s_3 and on par with the treatment s_5.

At 60, 90 and 120 DAP, s_5 proved superior. The leaf area values computed were 1464.84 cm^2 in the first and 1385.18 cm^2 in the second year respectively at 60 DAP and comparable to s_3. The leaf area in s_5 at 90 DAP (1499.06 cm^2 and 1448.06 cm^2), were on par with s_3 during first year and with s_3 and s_4 during the second year. The trend remained the similar at 120 DAP during the first year and second year of experimentation.

4.2.3. Physiological and Biochemical Parameters

4.2.3.1 Chlorophyll Content

The data on the chlorophyll content at 45 days interval as influenced by CO_2 fertilization are presented in Table 34. Perusal of data revealed the significant differences in chlorophyll content at 45 and 90 DAP.

At 45 DAP, the significantly highest chlorophyll content was recorded in s_3 during both the years (1.147 and 1.193 mg g^{-1}), followed by the treatment s_5 (s_3 + *Pleurotus* 1g kg^{-1} + N + P @ 2% w/w). However at 90 DAP during both the years of experimentation, the significantly superior chlorophyll content was recorded by the treatment s_5 (1.153 and 1.193 mg g^{-1}). The significant variations did not persist towards the later stages, during both the years.

4.2.3.2 Days to Senescence

The data on the number of days taken for the start of senescence in different treatments (Table 34) indicated that senescence was delayed in plants grown without CO_2 fertilization (no substrate) compared to the CO_2 fertilized plants. The number of days for the initiation of senescence was 223.0 in the first year, and 125.7, in the second year.

4.2.3.3 Biomass Partitioning at the Start of Senescence

The biomass partitioning in the plants at the start of senescence as influenced by elevated CO_2 is depicted in Table 35. It was evident that maximum accumulation occurred in stem followed by leaves and roots and the trend remained similar in both years. The treatment cow dung + coir pith (2:1) + *Pleurotus* + N + P (s_5) recorded significantly the highest stem, leaf, root and total biomass of the plant with the values 20.09, 12.30, 1.53 and 33.92 g per plant during the first year and 18.52, 10.67, 1.56 and 30.75 g per plant during the second year respectively and it remained the lowest when grown without substrate application. The corresponding percentage biomass partitioning to stem, leaves and root are 60.23, 34.70 and 5.07 during first year and 59.23, 36.26 and 4.51 respectively.

4.2.4 Yield Attributes and Yield

The crop was maintained in the trenches up to 238 days during the first year. Plants were pulled out two weeks after the initiation of senescence. The plants in all the treatments were found to be devoid of tubers.

Table 34. Effect of CO_2 fertilization on chlorophyll content and days to senescence

Treatments	Chlorophyll content (mg g^{-1})						Days to senescence	
	2019-20			2020-21			2019-20	2020-21
	45 DAP	90 DAP	135 DAP	45 DAP	90 DAP	135 DAP		
s_0: No substrate	0.837	0.904	0.924	0.867	0.891	0.558	223.0	125.7
s_1: Cow dung	0.944	0.956	0.970	0.961	0.946	0.579	218.3	122.3
s_2: Coir pith	0.932	0.955	0.967	0.942	0.952	0.596	220.3	123.0
s_3: Cow dung + Coir pith (2:1)	1.147	0.993	1.006	1.193	0.986	0.559	216.7	119.3
s_4: s_2 + *Pleurotus* + N + P	0.897	0.969	1.002	0.913	0.956	0.527	217.0	120.7
s_5: s_3 + *Pleurotus* + N + P	0.948	1.153	1.138	0.968	1.193	0.605	215.7	118.0
SEm (±)	0.020	0.015	0.039	0.038	0.023	0.025	0.9	0.7
CD (0.05)	0.0620	0.0459	NS	0.1176	0.0701	NS	2.87	2.01

Table 35. Effect of CO_2 fertilization on biomass partitioning, g per plant

Treatments	Biomass partitioning							
	2019-20				2020-21			
	Stem	Leaf	Root	Total	Stem	Leaf	Root	Total
s_0: No substrate	13.17	8.75	1.10	23.02	11.41	7.45	1.12	19.98
s_1: Cow dung	15.51	10.24	1.30	27.05	13.65	8.96	1.33	23.94
s_2: Coir pith	15.10	9.94	1.23	26.26	13.43	8.44	1.27	23.14
s_3: Cow dung + Coir pith (2:1)	17.79	11.06	1.39	30.24	16.12	9.54	1.42	27.08
s_4: s_2 + *Pleurotus* + N + P	16.75	10.95	1.31	29.01	15.75	9.38	1.37	26.50
s_5: s_3 + *Pleurotus* + N + P	20.09	12.30	1.53	33.92	18.52	10.67	1.56	30.75
SEm (±)	0.40	0.29	0.03	0.47	0.59	0.29	0.04	0.74
CD (0.05)	1.219	0.880	0.087	1.438	1.820	0.890	0.128	2.265

Table 36. Effect of CO_2 fertilization on nutrient uptake, g per plant

Treatments	Nutrient uptake					
	2019-20			2020-21		
	N uptake	P uptake	K uptake	N uptake	P uptake	K uptake
s_0: No substrate	0.255	0.135	0.500	0.240	0.142	0.480
s_1: Cow dung	0.280	0.128	0.517	0.270	0.132	0.514
s_2: Coir pith	0.273	0.124	0.543	0.259	0.120	0.534
s_3: Cow dung + Coir pith (2:1)	0.294	0.129	0.560	0.287	0.133	0.550
s_4: s_2 + *Pleurotus* + N + P	0.298	0.132	0.576	0.291	0.135	0.569
s_5: s_3 + *Pleurotus* + N + P	0.322	0.151	0.629	0.296	0.148	0.625
SEm (±)	0.012	0.005	0.022	0.010	0.004	0.025
CD (0.05)	NS	NS	NS	NS	NS	NS

Table 37. Changes in C: N ratio of the substrate with CO_2 release

Treatments	C:N ratio			
	2019-20		2020-21	
	Before	After	Before	After
s_0: No substrate	-	-	-	-
s_1: Cow dung	23.5	3.3	22.6	3.8
s_2: Coir pith	70.1	20.6	60.5	21.1
s_3: Cow dung + Coir pith (2:1)	46.8	4.1	42.4	4.4
s_4: s_2 + *Pleurotus* + N + P	11.7	3.8	11.1	4.2
s_5: s_3 + *Pleurotus* + N + P	10.3	3.5	11.0	4.1

In the second year, the crop was maintained up to 146 DAP in grow bags and when harvested, tuber initiation and formation were not seen in any of the treatments.

4.2.5 Pest and Disease Incidence

Neither pest nor disease incidence was observed during experimentation.

4.2.6 Quality Attributes of Tuber

As tubers were not formed, the quality attributes could not be assessed in the experiment.

4.2.7 Plant Analysis

4.2.7.1 Uptake of NPK

The data on NPK uptake by the plant as influenced by elevated CO_2 in trenches are presented in Table 36. Perusal of data revealed that, N, P and K uptake remained comparable with no significant variations during both the years.

4.2.8 Substrate Analysis

4.2.8.1 C: N ratio of Substrate (Before and After Experiment)

Data on C: N ratio of substrates (before and after the experiment) are presented in Table 37. Comparing the C: N ratio of the substrates used for CO_2 evolution, the widest C: N ratio was estimated in the coir pith (s_2) during first year (70.1:1) and second year (60.5:1). The lowest C: N ratio was in the substrate containing cow dung and coir pith augmented with *Pleurotus* and N and P (s_5). The C: N ratio of the decomposed substrate on the soil surface in the trench after the experiment was narrower than the initial values, but the ratio was maximum in s_2 during both the years (20.6:1 and 21.1:1 respectively during the first and second year) compared to the other substrates, and the lowest was in s_1.

4.2.9 Soil Analysis

4.2.9.1 Soil Organic Carbon

The perusal of data on the changes in organic carbon status of soil with substrate addition and CO_2 evolution (Table 38) showed no significant difference when the plants were grown in soil in the trench in the first year and in grow bags kept in trenches in the second year.

The results reveal enhanced vegetative growth in Chinese potato in response to CO_2 fertilization in the trench system explored in the study with and without substrates as sources of CO_2.

Table 38. Effect of CO_2 fertilization on soil organic carbon after experiment, per cent

Treatments	Organic carbon	
	2019-20	2020-21
s_0: No substrate	0.81	0.75
s_1: Cow dung	0.77	0.73
s_2: Coir pith	0.81	0.78
s_3: Cow dung + Coir pith (2:1)	0.74	0.70
s_4: s_2 + *Pleurotus* + N + P	0.84	0.80
s_5: s_3 + *Pleurotus* + N + P	0.76	0.73
SEm (±)	0.04	0.05
CD	NS	NS

DISCUSSION

5. DISCUSSION

The investigation entitled "Resource management for source - sink modulation in Chinese potato [*Plectranthus rotundifolius* (Poir.) Spreng.]" was undertaken with the objectives to study the influence of planting methods, nutrient management practices and growth promoters on source - sink relationship, tuber yield and quality in Chinese potato, to assess the growth and yield responses of the crop to carbon dioxide fertilization and to work out the economics. The results of the experiments detailed in Chapter 4 are discussed in this section with available documented literature.

5.1 EXPERIMENT I: INFLUENCE OF METHOD OF PLANTING, NUTRIENT MANAGEMENT AND GROWTH PROMOTERS ON SOURCE - SINK RELATIONSHIP, TUBER YIELD AND QUALITY IN CHINESE POTATO

5.1.1 Growth Attributes

Growth attributes in Chinese potato were significantly influenced by method of planting and nutrient management + growth promoter combination and their interaction. Plants were taller in the bed and ridge method of planting at the closer spacing (30 cm x 15 cm) compared to the wider spaced planting on beds, ridges and mounds. Planting geometry brought about differences in the plant population at the two spacings. The plant population in narrow spacing (22.22 plants per m^2) was twice that under the wider spacing. Hence, variations in the growth and growth attributes were expected. The closer spacing resulted in better canopy coverage, but reduced the light penetration through canopy resulting in etiolation of plants. This was expressed as an increased plant height and hence taller plants. Rao (2005) reported higher inter-nodal length and thereby taller plants in coleus with reduced spacing. It is also reasoned that under closer spacing, the endogenous auxins which are less prone to photo-oxidation and destruction under low light conditions, are produced (Nadukeri and Kattimani, 2008), and these promoted cell division and enlargement in the apical meristem (Behringer and Davies, 1992), resulting in taller plants.

Nevertheless, the vegetative growth gauged in terms of number of branches per plant, plant spread, leaf number and leaf area recorded were higher at the wider spacing of 30 cm x 30 cm in the bed and the ridge methods of planting. As growth advanced, the plant spread (N-S and E-W direction) increased upto 90 DAP, whereas leaf number and leaf area per plant were maximum at 45 DAP and declined thereafter.

Land configuration and method of planting have profound influence on the growth and yield performance of plants, especially in tuber crops (Ennin *et al*., 2009; Byju *et al*., 2010 Nedunchezhiyan *et al*., 2012; Dlamini *et al*., 2021). Tuberisation occurs in soil and any management practice that loosens soil, endorses favourable soil moisture status and promotes bulking of tubers, is considered ideal. Compared to the mound method of planting, bed and ridge methods were superior which may be attributed to the variations in soil properties that enhanced root growth, proliferation, water retention and uptake.

The vegetative growth parameters, number of branches, number of leaves and leaf area per plant were higher in the bed method, but on par with the ridge method of planting. The levelled surface of the beds ensured better water retention compared to the mounds and ridges.

Research studies have shown that planting potatoes on a bed configuration could ensure a better and more uniform distribution of water in the root zone (Prestt and Carr, 1984). Robinson (1999), based on the experiments in potato opined that crops planted in beds were more efficient in capturing water as the flat bed enhanced water infiltration around the crop. The sloped sides of the ridges and mounds can impede the penetration of water in soil and hence reaching the crop root zone. The author added that as the crop establishes, the canopy may serve as an umbrella allowing water to drip into the furrows. On the contrary, the canopy can also have a positive effect; guide the falling water to flow down the stem and infiltrate at the base directly onto the potatoes. However, this was not observed in the field as the weight of water on the leaves caused them to bent as a result of which the intercepted water falls onto the furrows rather than on the ridges. Essah and Honeycutt (2004) observed that raised beds in potato systems increased the amount of water that was captured on the soil surface compared to ridged rows where more water was directed into furrows due to the side slopes of the ridges, leading to lowered water retention in the root zone. Chawla *et al.* (2018) elucidated that raised bed planting had favourable effects on growth and yield of tuberose as compared to ridge and furrow method of planting. Raised beds increased water productivity and nitrogen use efficiency by reduced leaching compared to other methods of planting (Hashimi *et al.*, 2019) and according to Subhash *et al.* (2020), broad bed furrow system improved soil structure, enhanced the nutrient mineralisation, transformation and their availability for plant growth.

In ridges, the loose soil with better aeration favoured root growth, better uptake and shoot development and could yield on par results with the bed method compensating for the lower water retention. Akinboye *et al.* (2015) documented a similar observation evaluating the land configuration methods ideal in sweet potato.

With respect to the plant spread, the ridge planting method ensued slightly higher values than the bed method but were comparable. Sajjapongse and Roan (1982) documented higher plant spread in sweet potato with the ridge method of planting. Ridging was found to be superior over mounding in the current study and accords to the findings in sweet potato by Ennin *et al.* (2003). A significant observation by Agbede and Adekiya (2009) was that although ridges and mounds have the advantages of a loose soil free of compaction, compared to ridges, the mounds have a slightly higher temperature as these are isolated and subjected to the beating by sun rays from many angles causing an early drying of soil on all sides due to excessive evaporation which has a bearing on root growth.

The wider spacing (30 cm x 30 cm) reduced the competition for growth resources mainly water, nutrients and sunlight and hence led to a higher availability of per plant resources which contributed to the production of higher number of branches, plant spread, number of leaves and leaf area. Light is one of the important factors responsible for increasing productivity of crops and the solar radiation is the source of energy for photosynthesis. It is deduced that better light penetration in the widely spaced plants ensured more photosynthesis including that in the lower leaves, and contributed to higher values of per plant growth attributes enhancing the source potential. Increased number of branches with wider spacing was earlier reported by Hamid and Sasaki (2001) in sweet potato cultivars. The results are also in accordance with the findings of Bharathi *et al*. (2004) who reported the highest number of branches, plant spread and number of leaves in chinese potato under wider spacing. Higher leaf area in medicinal coleus (Rao and Reddy, 2005) and number of compound leaves in potato (Sharma *et al*., 2014) in widely spaced plants also support the findings of the present study.

Among the nutrient management + growth promoter combinations, superiority of the combinations involving PGPR Mix 1 (n_1) on growth attributes *viz*., plant height, number of branches per plant and plant spread at 30 DAP and number of leaves and leaf area at 45 DAP were evident. At the later stages of growth, the effect of humic acid in combination with NPK and PGPR Mix 1 (n_1g_1) on plant height were perceptible during both the years as these were applied only at 45 and 75 DAP .

The biofertilizer consortium, PGPR Mix 1 used, included the microorganisms, N fixers (*Azospirillum lipoferum, Azotobacter chroococcum*), P solubilizer (*Bacillus megaterium*) and K solubilizer (*Bacillus sporothermodurans*) each of which play a significant role in enhancing the availability of nutrients primarily N, P and K in soil for plant uptake. Dobbelaere *et al*. (2001) opined that the PGPRs, especially *Azospirillum lipoferum,* in addition to the N fixing capacity promote plant growth on account of its ability to produce various phyto hormones. Similarly *Azotobacter chroococcum,* though generally regarded as a free-living aerobic nitrogen fixer, evidences indicate that it influences the plant growth and development by production of phytohormones *viz*., auxins, cytokinins and gibberellins (Saharan and Nehra, 2011). Phosphorus and K solubilising bacteria increased mineral availability from rock materials (P and K rocks), uptake and plant growth suggesting the potential use of the microbe augmented material as a fertilizer (Supanjani *et al*., 2006).

Phosphorus solubilizing bacteria (PSB) have been shown to supplement the solubilization of insoluble P compounds through the release of organic acids and phosphatase enzymes (Sahu and Jana, 2000). The bacteria are widely used as inoculants for enhanced P use efficiency by solubilizing insoluble P in soils (Sundara *et al*., 2002; Dey *et al*., 2004).

The potential benefits of K solubilizers in the natural K cycle and impacts on K availablity for uptake have been illustrated (Lian *et al*., 2008). The bacteria exude organic acids, siderophores, and hydrogen ions, that result in K being mobilized from minerals such as illite, feldspar, and micas (Lian *et al*., 2002; Liu *et al*., 2012).

Thus, the mechanisms consisting of the supply of nutrients to the plant, either by N fixation or by P/K solubilisation and increased iron bioavailability (through siderophore production) coupled with the production of phytohormones, contributed to better plant growth when consortium biofertilizers are used (Ferreira *et al*., 2019). The nutrient dose of 60:30:120 NPK kg ha^{-1} coupled with the PGPR application could thus ensure adequate nutrient supply and nutrient use efficiency compared to sole application of nutrients alone.

Evidences on PGPR inoculation enhancing the uptake of mineral nutrient P, K, Ca and Mg are available (Sheng, 2005). Jayapal (2012) reported a notably increased number of leaves in coleus, 30 DAP, with the application of PGPR Mix 1 at 2 per cent in conjunction with the basal dose of organic manures. Similarly in cassava, Babu (2020) recorded higher number of branches with the inclusion of PGPR Mix 1 in its nutrient management compared to that without PGPR application. Increased growth in the inoculated plants can also be ascribed to the beneficial effects of enhanced microbial activity in the crop root zone as augmentation of the rhizosphere microbiome has favourable influences on root growth, nutrient availability and uptake (Devaraj, 2021).

The beneficial effect of humic acid on plant growth is attributed to the favourable biochemical environment provided within plants and hormonal effects (Nikbakht *et al*., 2008). The congenial effects include increased cell membrane permeability, increased photosynthesis and respiration rates, enhanced mineral uptake, protein synthesis and hormone-like activity. El-Bassiouny *et al*. (2014) postulated that humic acid is not a fertilizer as it does not directly provide nutrients to plants, but a compliment to fertilizer. According to the authors, the application, amended with nutrient sources, could significantly improve all morphological characteristics (plant height, leaves number, fresh and dry weights of shoots), metabolism (photosynthetic pigment, total soluble sugar, total carbohydrates, total amino acids and proline), mineral contents (N, P, K, Ca and Mg) and yield (grain, straw and biology) in durum wheat.

Humic acid application promotes the overall metabolism in crop plants and total photosynthetic rate (Srivastava, 1995; Zeng, 2002). As per the reports of Zhang *et al*. (2003), foliar application of humic acid increased the super dismutase antioxidant and associated photochemical activities improving the physiological health in bent grass. Supplementation with fertilizers could bolster the plant defense mechanisms reducing the incidence of pests and diseases in crops. Arafa and El-Howeity (2017), elaborated that humic acid influences cell division and elongation as well as the physiological functions of the cells, which consequently modifies plant growth.

The improved biometric characters of Chinese potato observed in this study due to application of humic acid are on account of its effect on increasing the biological interactions within the plant tissues, N metabolism and protein synthesis as observed by Baldotto and Baldotto (2013) in gladiolus. The better interception of light evinced reflected positively on the metabolic activities and hence morphology of the plant (Nayyef and Hammadi, 2021). Taken together, plant growth promoting bacteria driven nutrient availability, hormone production and changes in phenolic metabolism by humic substances could be responsible for increased vegetative growth.

Benzyl adenine (BA) is reported to retard leaf senescence (Hadas *et al*., 1996; Mutui *et al*., 2003) and Adedipe *et al*. (1971) had earlier documented that it is associated with the maintenance of photosynthetic activity for a longer period. The inhibitory action of BA on leaf senescence is assumed to be due to the reduced biosynthesis of ethylene that has a crucial role in the regulation of leaf senescence (Iqbal *et al*., 2017). Among the phytohormones produced by the microorganisms present in the PGPR, cytokinins influence chlorophyll production and delay senescence (Wong *et al*., 2015). Parmar *et al*. (2021) observed that BA acts as antisenescent, stops the metabolic break down and deterioration caused by various biochemical activities and enhances the cell division and chlorophyll accumulation which lead to higher photosynthetic activity. This could explain the significantly higher number of leaves and leaf area per plant at 135 DAP recorded with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA (n_1g_2).

Planting at a wider spacing, either on beds or ridges, along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid resulted in higher number of branches, plant spread, number of leaves and leaf area. The superiority of bed or ridge method of planting with a spacing of 30 cm x 15 cm along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid on plant height noticed is assessed as the emulation of the individual effects of treatments. The comparable effects produced by the treatments containing 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 (n_1) irrespective of growth promoter on plant height, number of branches and plant spread at 30 DAP and number of leaves and leaf area at 45 DAP were also echoed in interaction effect. There was a decreasing trend in number of branches towards harvest which is due to the progressive senescence as observed by Jayapal (2012) and Anju (2014) in Chinese potato.

5.1.2 Yield Attributes and Yield

The tuber attributes and yields were found to vary markedly with the method of planting, nutrient management + growth promoter combination and their interaction (Fig. 7a to 9b) . Bed or ridge method of planting at wider spacing (30 cm x 30 cm) registered the maximum number per plant, tuber yields and harvest index during both the years.

Productivity of a crop largely depends on various growth attributes (Sen *et al.,* 2010). The physical conditions of the soil influence plant growth and development, and hence proper tillage/land preparation is necessary for realizing the full yield potential of the crop (George *et al*., 2000). This is of greater significance in tuber crops as the economic part develops within the soil. Rani *et al*. (2008) stated that the soil physical environment has a critical role in influencing the development of tubers in coleus. An improved and favourable soil physical environment led to increased the yield parameters in medicinal coleus (Ravikumar *et al*., 2013; Tanuja *et al*., 2013).

The improved physical condition in the bed method of planting favourably influenced the yield attributes. Better number and yield of tubers with bed method of planting can be attributed to the comparatively larger space available for the growth and ramification of underground plant parts on account of the levelled covering of whole intra row spaces with soil media in comparison to the ridge and furrow method (Sharma *et al*., 2014). They also reported reduction in the proportion of small sized tubers with wider spacing which was reflected in the percentage number of marketable tubers per plant. Similar results were observed in the present study as higher percentage of marketable tubers under wider spacing. The better yield attributes realized with the bed method of planting at wider spacing are a manifestation of the efficient vegetative growth, source strength, indicated by the higher number of branches, leaves and leaf area

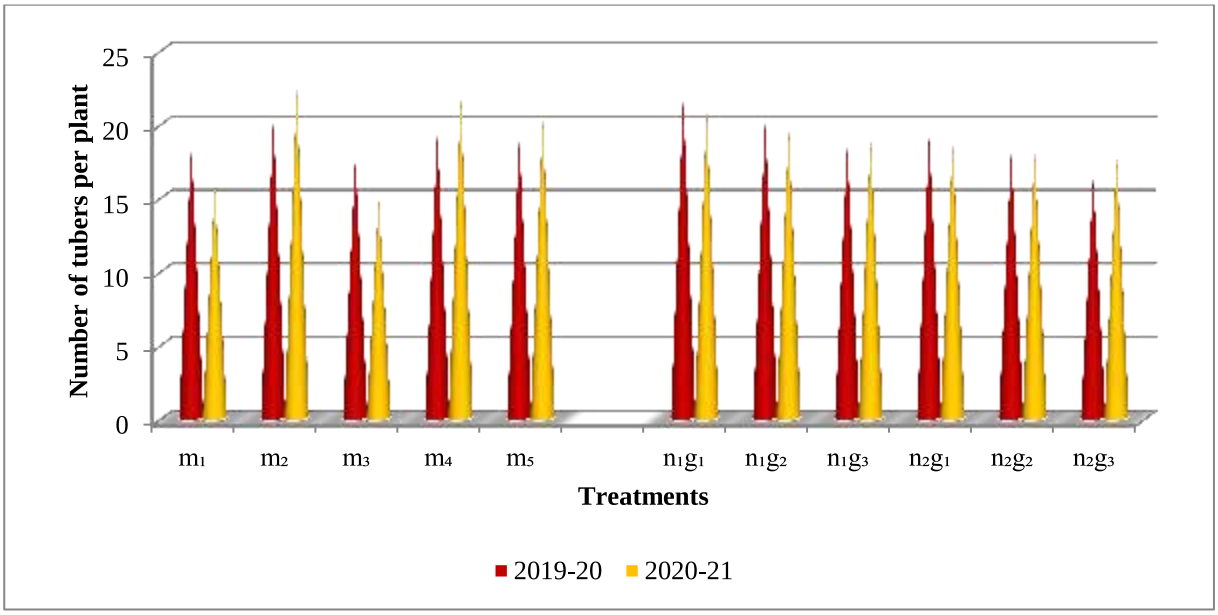


Fig.7a. Effect of method of planting and nutrient management x growth promoters on number of tubers per plant

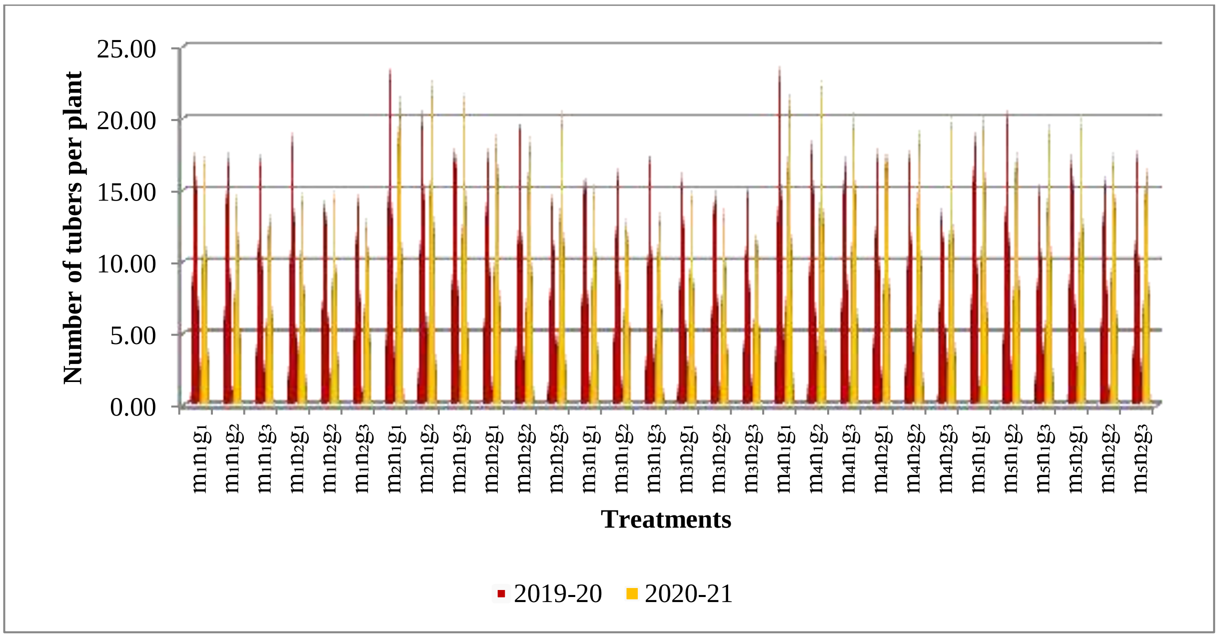


Fig. 7b. Interaction effect of method of planting x nutrient management + growth promoters on number of tubers per plant

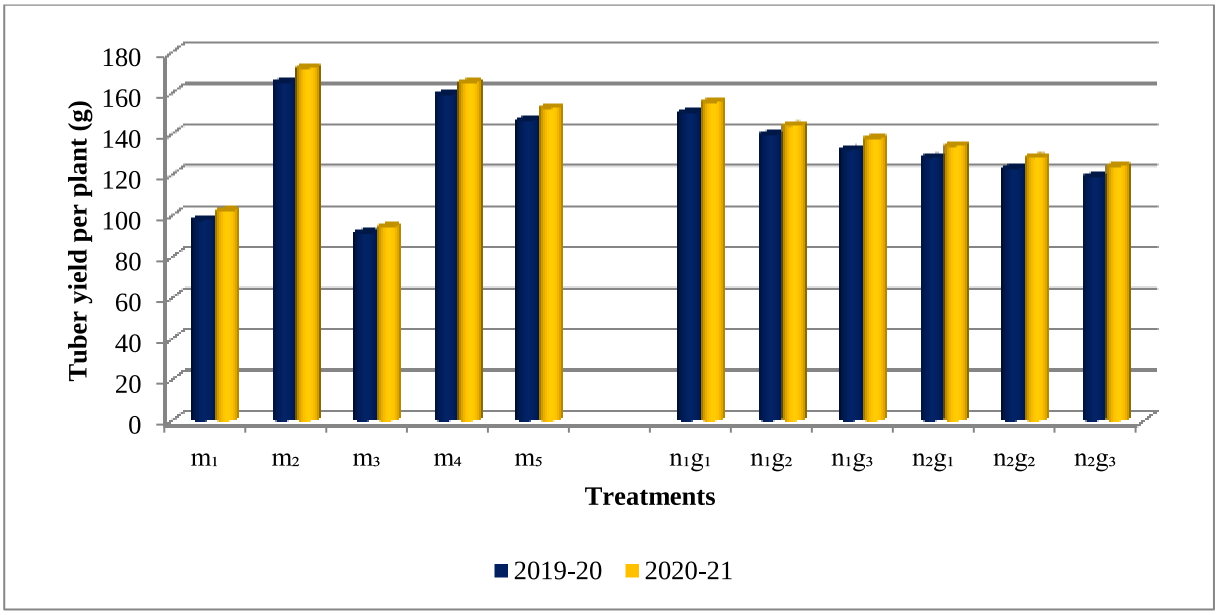


Fig. 8a. Effect of method of planting and nutrient management x growth promoters on tuber yield per plant, g

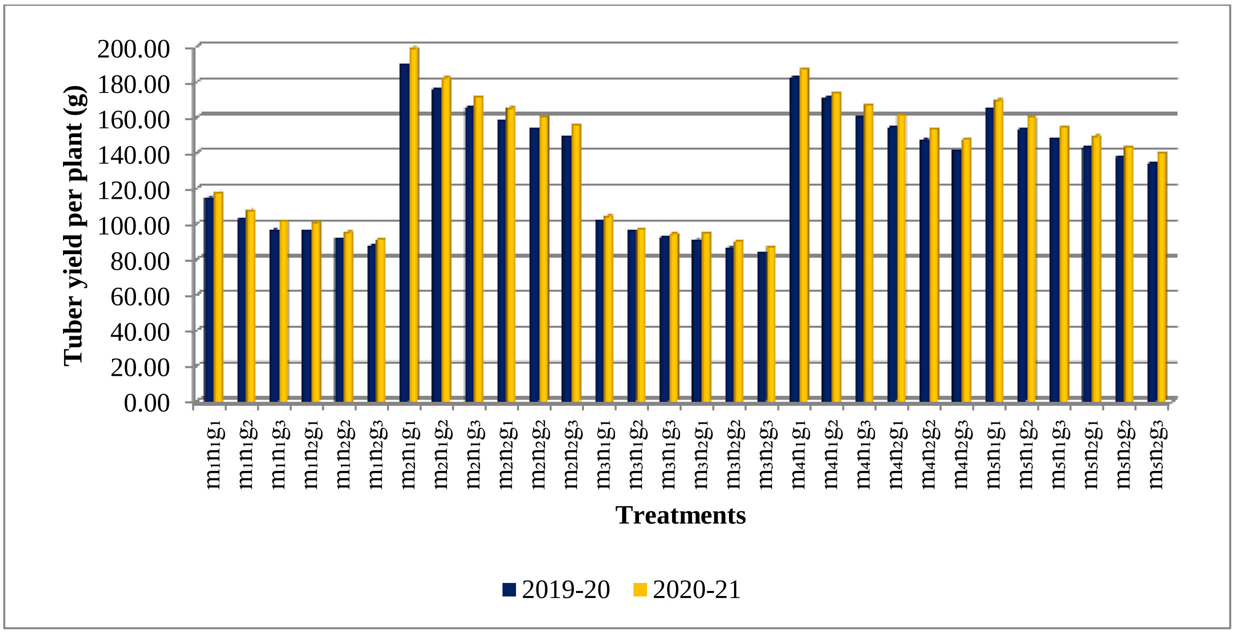


Fig. 8b. Interaction effect of method of planting x nutrient management + growth promoters on tuber yield per plant, g

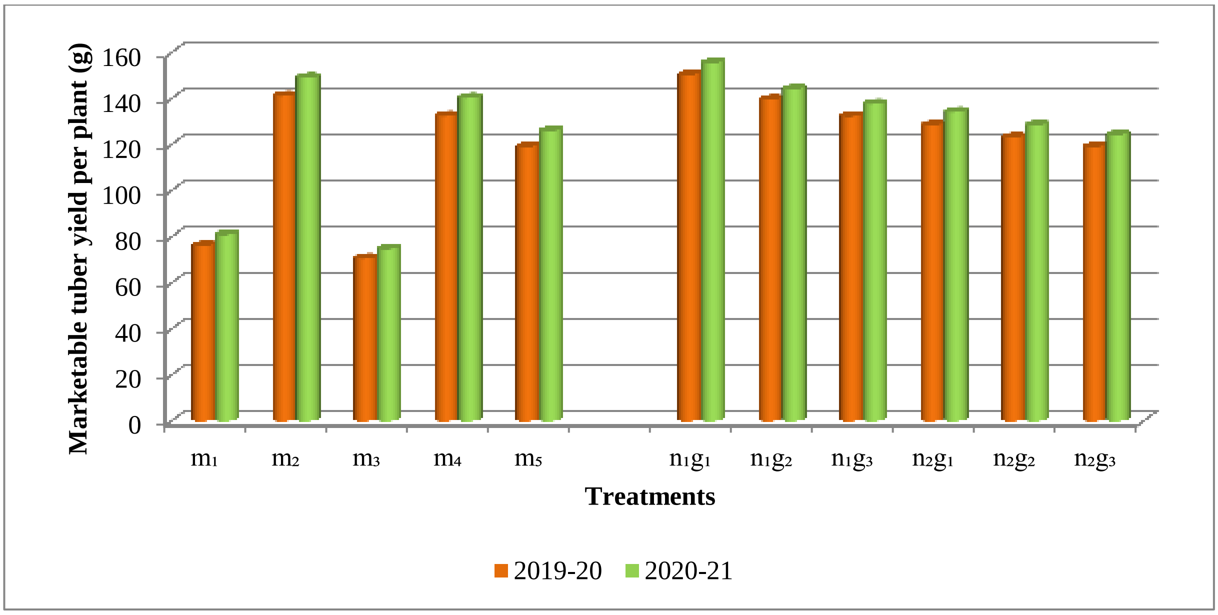


Fig. 9a. Effect of method of planting and nutrient management x growth promoters on marketable tuber yield per plant, g

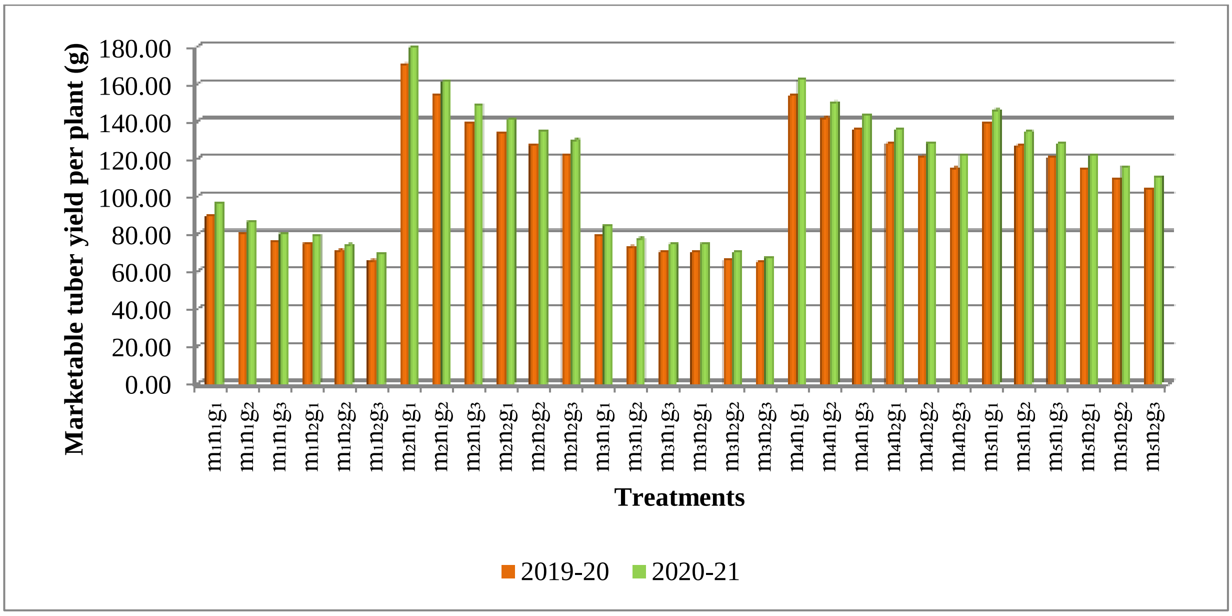


Fig. 9b. Interaction effect of method of planting x nutrient management + growth promoters on marketable tuber yield per plant, g

obtained in this treatment. The widely spaced plants were benefitted with the better access and utilization of the resources which fuelled the growth attributes. The differences in per plant tuber yield among spacing levels arose largely because of differences in the yield components. Vegetative growth, particularly the higher number of branches per plant led to the significantly higher per plant tuber yield in sweet potato (Saqib *et al.* , 2017).

Unlike the field crops in which reproductive stage is crucial for deciding the yield, in tubers, the yield components are vegetative structures itself. There is no transition from the vegetative to the reproductive phase for economic yield realisation. Ivins (1973) documented that the management options for improving yields vary with the crops. In cereals, it was suggested that the main aim should be to extend the interval between anthesis and time of ripening, while in potato, it should focus on breaking the apparent linkage between early tuber initiation and early leaf senescence to give a longer period of tuber bulking.

Per hectare tuber yield and marketable tuber yield were significantly the highest in bed method of planting with closer spacing of 30 cm x 15 cm [20.93 and 17.46 t ha^{-1}(pooled)] as depicted in Fig. 10a. Increase in plant density directly influenced the per hectare tuber yield and correspondingly, the marketable tuber yield. Percentage marketable tuber yield was also higher in bed method of planting at 30 cm x 30 cm spacing (m_2). The higher plant density under narrow spacing (30 cm x 15 cm) resulted in better canopy coverage and LAI indicating a reinforced source capacity and photosynthetic ability contributing to the tuber sinks and higher yields. It is surmised that the accruement is mainly due to the increase in plant population despite a compromise in per plant yields. Rao (2005) recorded maximum fresh weight of roots in medicinal coleus with flat bed method of planting compared to ridges and dry root yield, with closer spacing of 60 cm x 20 cm. Increased tuber yield and marketable yield with closer spacing were also documented in potato (Kumar *et al*., 2009; Aminifard *et al*., 2012).

Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) recorded the significantly highest yield attributes and yield in both the years. Inclusion of PGPR along with humic acid in the nutrient management strategy could result in 25.2 to 26.4 per cent increase in the per plant yields and 19.7 to 21.7 per cent increase in the per hectare yields compared to that without PGPR and humic acid.

Chemical fertilizers are the most preferred source of nutrients in crop production. Nevertheless, the nutrient use efficiency is reported to be low (Zhang and Ma, 2000; Pathak *et al*., 2003). Many a time, the nutrients are rendered unavailable either *via* fixation or being lost from the soil. Biofertilizers have a prominent role in improving nutrient availability and also escalate the microbial activities in the rhizosphere creating a favourable niche for root growth and tuber development. The role in improving plant nutition and enzyme activation has also been ascertained (Meena *et al*., 2014). Initial soil status revealed that it was medium in available N and high in available P and K. However, the dynamics of P and K in soil are highly complex and a high status need not necessarily assure increased availability. Inclusion of biofertilizers can strategically stimulate and make available the soil nutrients. Hence it is deduced that the application of PGPR along with inorganic fertilizers could enhance the nutrient availability and hence absorption from soil.

Plant Growth Promoting Rhizobacteria act as a complement to inorganic ferilizers by N fixation and P solubilization (Tahir and Sarwar., 2013). The K solubilizers augment plant growth by solubilization of minerals (Sheng and Huang, 2002), and synthesis of phytohormones (Kumar, P *et al*., 2012). The PGPR Mix 1 developed in KAU evaluated in Chinese potato (Jayapal, 2012) proved promising. Gopi *et al*. (2020) opined that application of liquid formulation of PGPR mixture helps to reduce the inorganic fertilizer requirement in amaranthus. They observed that the effective contribution of N by the two diazotrophs (*Azospirillum* and *Azotobacter*) present in PGPR Mix 1 and the P and K solubilization by *Bacillus* sp could reduce chemical fertilizer use by 50 per cent.

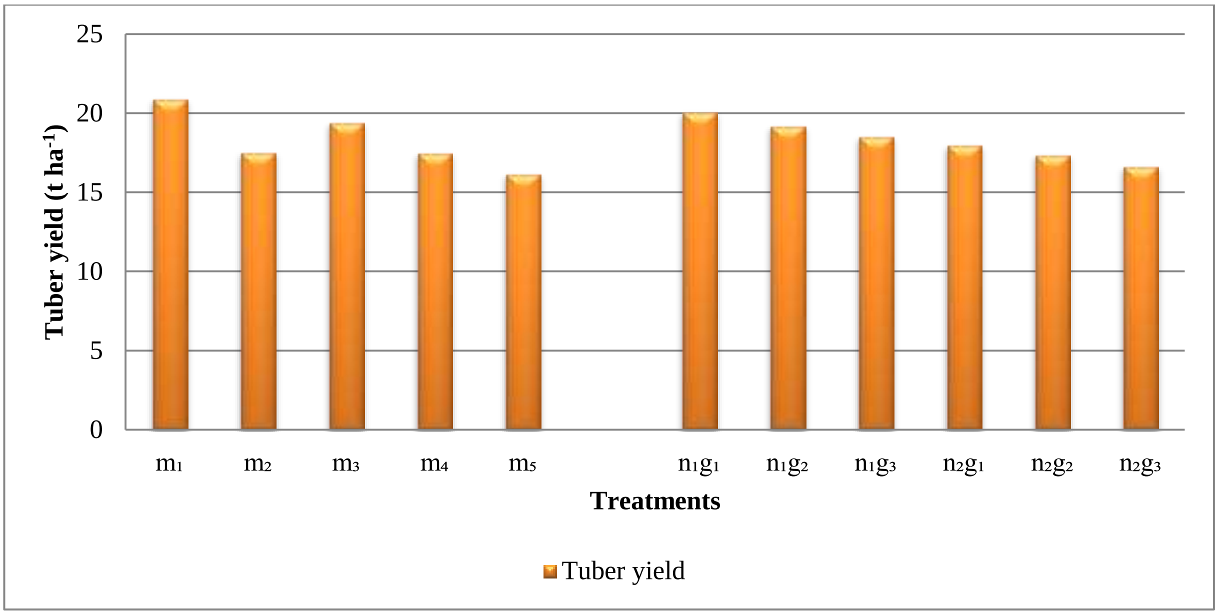


Fig.10a. Effect of method of planting and nutrient management x growth promoters on per hectare tuber yield (pooled mean), t ha^{-1}

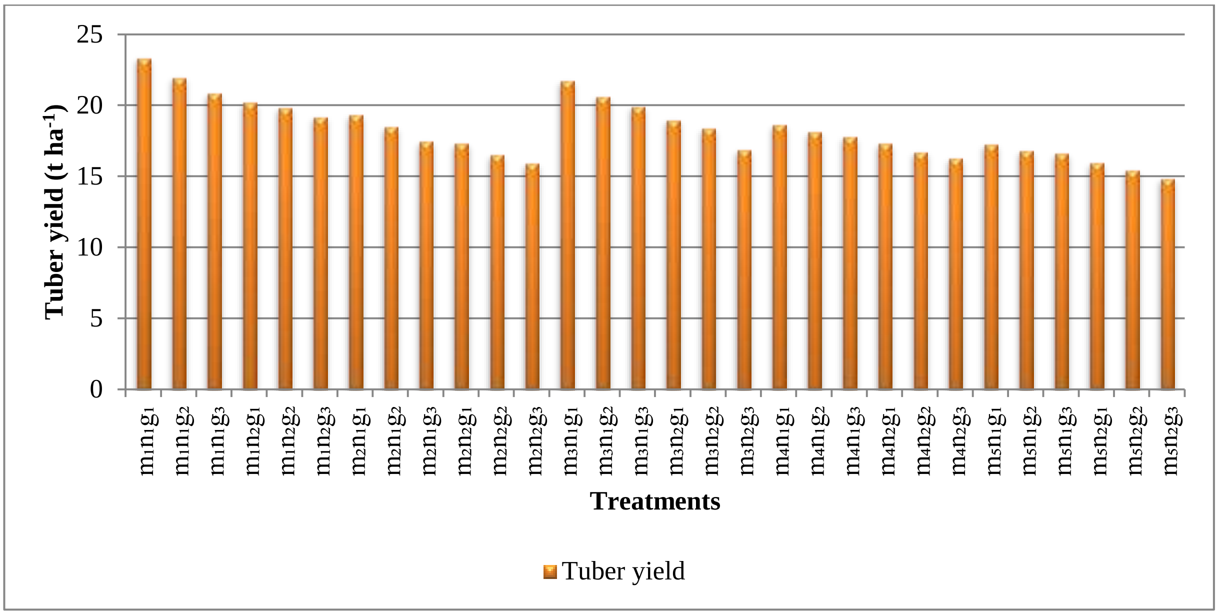


Fig. 10b. Interaction effect of method of planting x nutrient management + growth promoters on per hectare tuber yield (pooled mean), t ha^{-1}

Increased or on par yields with the inclusion of PGPR have been reported by several workers (Javed and Arshad, 1999; Yasmin *et al.,* 2007; Ekin *et al*., 2009).

Morphological and physiological changes in plants and enhancement of nutrient content were significantly influenced by the growth promoting effects of PGPR (Amir *et al.,* 2005; Mia *et al.,* 2010). Indole Acetic acid (IAA) producing PGPR are believed to increase root growth and root length, resulting in greater root surface area which enabled the plant to access more nutrients from the soil (Vessey, 2003; Chaiharn and Lumyong, 2011) and finally aided in higher sweet potato yields (Yasmin *et al*., 2020). Babu (2020) recorded significantly higher number of tubers per plant and per hectare yields with PGPR Mix 1 application in cassava.

Among the growth promoters used (BA and humic acid), the addition of humic acid along with PGPR was found to be superior. The increases recorded in per plant yields over BA application were 7.7 and 13 per cent in the first and second year respectively and that in per hectare yields averaged 4.5 per cent in both years. Sangeetha and Singaram (2007) attributed the accelerated photosynthesis and translocation to the bulbs in onion, to the indirect effect of humic acid whereas Nikbakht *et al*. (2008) ascribed the increased yield attributes and yield in gerbera with application of humic acid to the effect on root growth indicating a probably greater recourse allocation of photosynthates to the roots.

El-Deen *et al*. (2011) observed significantly higher tuber weight, marketable tuber yield and total tuber yield with the application of humic acid compared to that without its application in sweet potato. Similar results in potato were documented by different authors (Radwan *et al*., 2011; Juboori *et al*., 2012; Shah *et al*., 2016). It also needs to be mentioned that in the current study, even among the treatments without PGPR, humic acid manifested its superiority. The improved nutrient status of plants due to hormonal effect of humic acid (Tables 22a and 22b) would also have contributed to the higher yield. The results are agreement with those reported by Ezzat *et al.* (2009).

Sathiyaraj (2017) attributed the increased fresh and dry weight of tubers in *Coleus forskohlii* to the humic substances which would have mobilized the reserve food materials to the sink through increased activity of hydrolyzing and oxidizing enzymes. This is in accordance with the reports of Verlinden *et al.* (2009) who documented that humic acid application increased total yield and marketable yield of potato crop. Selim *et al.* (2009) observed that co-administration of humic acid and 100 per cent NPK was more efficient in stimulating potato tuber growth than the recommended fertilizer alone. Improved tuber growth with the application of PGPR strains in combination with humic acids may be positively correlated with higher photosynthetic rates due to the availability of sufficient nutrient elements and increased water use efficiency as ascertained by Ekin (2019) in potato. It is also hypothesised that the presence of humic acid enhanced the upregulation of genes related to signal transduction, hormone metabolism, transcription, protein metabolism, transport, defense, and growth related processes in terms of number of involved genes (Galambos *et al.*, 2020) which would have a bearing on the growth and yield performance of crops.

Assessing the interaction effects, the per plant tuber yields (number of tubers per plant, tuber yield per plant and marketable tuber yield per plant) were the highest in the treatment combination of bed method of planting at 30 cm x 30 cm along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid ($m_2n_1g_1$). Howbeit, per hectare yields were superior in the same input combination, but at 30 cm x 15 cm owing to the higher plant density. The increase assessed for pooled mean of per hectare yields was 20.83 percent (Fig. 10a and b). This is in line with the results of Bharathi *et al.* (2004) in Chinese potato. Bayorbor and Gumah (2007) reported an increased yield of 14.3 per cent with closer intra row spacing of 20 cm compared to wider intra-row spacing of 40 cm in Chinese potato.

Photosynthesis is the process by which plants synthesize food in the source organs like leaves, and the products, the photoassimilates, are then translocated to various plant parts including storage organs (sink). The yield of the

Plates 3a. Marketable and less marketable tubers

Plates 3b. Tuber yield as influenced by treatment combinations

crop is thus, apart from the genes in its genome, governed by source activity, translocation and accumulation in sink (Howlader *et al*., 2018).

The factors regulating source and sink capacities include environmental, nutritional, metabolic and hormonal factors (Mitra *et al*., 1993). Light, water, and mineral nutrients are some of the primary factors which influence source and sink activities by their direct effect on photosynthesis and assimilate transfer. The primary objective of including plant growth regulators or phytohormones in crop production is to enhance productivity and this is made possible through the effects on photosynthesis, mobilization of assimilates and source-sink interaction (Warrier *et al.,* 1987). Plant growth regulators appear either to form an enhanced sink, mobilizing the different nutrients which are involved in building new tissues and/or to enhance the photosynthetic mechanism and protein synthesis (Taiz and Zeiger, 1998).

The favourable influences of the bed method of planting and inclusion of PGPR + humic acid along with the NPK doses on the biometric characters in Chinese potato have been discussed. It is deduced that the above management options enhanced the source strength of the crop through better canopy development, ensuring a higher rate of photosynthetic activity and production. Analyzing the effects on the per plant yields, a wider spacing was found superior. The increase in per hectare tuber yields at the closer spacing is due to the correspondingly higher number of plants per unit area. Adequate and balanced nutrition along with the favourable soil environment for tuberization would have favourably influenced the sink potential in terms of tuber number. The increased uptake of nutrients from soil with the integrated application of nutrients and biofertilizers (Tables 22a and 22b) would have produced enough carbohydrates in the source organs (leaves) for translocation to the sink organs (tuber) for better bulking and yield. In addition, humic acid application would have enhanced the mobilisation of the photoassimilates to the sink organs. These assumptions are confirmed with the significantly higher tuber weights, tuber yield and marketable yield realized in the combination. The higher LAI evinced in treatment combination in bed planting method at 30 cm x 15 cm spacing along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid and tuber yield indicated a better source-sink balance and hence better productivity. Further, the proportion of marketable tubers were also higher (10.26 %) compared to chemical fertilizer and water spray. Namo and Opaleye (2018) recorded that although many tubers were produced per plant in Hausa potato, they were of smaller size which can be assumed to be due to the slow rate of translocation of assimilates from the source to the sink which has been modulated with the treatments in the present study.

It is thus concluded that the land configuration (bed method) of planting the cuttings at 30 cm x 15 cm and nutrient management with NPK @ 60:30:120 kg ha^{-1}, PGPR Mix 1 and humic acid could favourably influence the source- sink relations in Chinese potato resulting in superior yields compared to the other management options evaluated in the study.

5.1.3 Physiological Attributes

Method of planting and nutrient management + growth promoter combination and their interaction exerted significant influence on physiological attributes of Chinese potato in the study. The variations in growth attributes brought by the differences in plant population at two spacings tried also ensued significant differences in the physiological attributes. The higher plant density with closer spacing of 30 cm x 15 cm recorded the significantly highest per hectare DMP, CGR and LAI. Chlorophyll content was higher in the bed or ridge planting method with wider spacing.

Crop growth rate, defined as the rate of dry matter accumulation per unit land area in crop stands is a useful growth parameter for estimating the production efficiency, and LAI indicates the photosynthetic efficiency of the plant. Irrespective of the treatments imposed, CGR was found to increase to a maximum at the maturity stages (90-135 DAP) stipulating the higher biomass accumulation due to tuber bulking.

The DMP, CGR and LAI computed revealed higher values in bed planting at closer spacing (m_1) and these correspond to the better growth and yield attributes observed in the treatment. The higher DMP is due to increased number of plants, whereas the highest CGR recorded is attributable to greater photosynthetic efficiency in closely spaced crop (Sen *et al*., 2014). Higher CGR recorded in the study are in accordance with the results of Malik (2000). Increased biomass production with closer spacing was also documented by Jayalakshmi (2003), Singh (2013) and Mastiholi *et al*. (2013).

Crop geometry showed a significant effect on LAI (Fig. 11a). Even though the closer spacing of 30 cm x 15 cm produced lower number of leaves and leaf area per plant compared to wider spacing, the higher plant population (22.22 per m^2) contributed to more number and area of leaves on unit area basis and hence a higher LAI . Veerana *et al.* (1997) reported an inverse relationship of LAI with crop spacing in potato confirming the present results. The observation falls in line with that reported by Suja and Nayar (2006); Bayorbor and Gumah (2007) and Sen *et al.* (2014).

Relative growth rate (RGR) and net assimilation rate (NAR) were higher in bed or ridge with wider spacing (30 cm x 30 cm). RGR and NAR decreased with increase in plant density (Enyi, 1973).

Net Assimilation Rate is negatively related to LAI (Watson, 1958). Enyi (1973) also reported similar results of a decrease in NAR with an increase in LAI in cassava. Singh (2013) adverted that physiological traits varied significantly due to spacing in *Coleus forskohlii* and documented the significant influence of spacing on leaf area, dry matter, LAI, CGR and RGR.

The superiority of the combinations containing PGPR Mix 1 (n_1) in physiological parameters *viz.* CGR, RGR, LAI, NAR and chlorophyll content at/ up to 45 DAP might be due to the growth enhancement and reinforced nutrient availability warranted by the plant growth promoting bacteria present in the biofertlizer consortium PGPR Mix 1. At this stage, as growth promoters were not applied the parameters, DMP, CGR and LAI remained comparable in the PGPR applied treatments. The positive influence of PGPR on growth and DMP observed is in accordance with the results in medicinal coleus (Priya and Kumutha, 2013).

At the later stages, the significant effect of the combination, 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid, was clearly visible. Humic acid is considered to increase the permeability of plant membranes and enhance the uptake of nutrients and has been proven effective in wheat (El-Bassiouny *et al*., 2014).

The effect of humic acid being complimentary to nutrient application has been illustrated by several workers. Mailappa (2003) observed improved growth in cassava with combined application of NPK and humic acid spray. The treatment combination involving organics and inorganics along with biofertilizer and humic acid spray resulted in the highest DMP in medicinal coleus (Sathiyaraj, 2017). In the present study also, an increased uptake of nutrients in humic acid involved treatments in combination with PGPR was discerned. This would have enhanced the DMP by virtue of its effect on the increased plant growth and yields.

Ferrara and Brunneti (2008) authenticated the increased photosynthetic pigment content (chlorophyll) with humic acid application as to that caused by an increase in the synthesis of the chlorophyll and/or delayed chlorophyll degradation in leaves. It is reasoned that the formation of larger and more number of bundle sheath chloroplast in the inoculated plants led to increased chlorophyll content (Arumugam *et al.,* 2010). The higher chlorophyll content in humic acid applied treatments corroborates the results reported by El-Deen *et al*. (2011) in sweet potato. According to Haghighi *et al*. (2012), it is the acceleration of N and nitrate uptake, enhancing N metabolism and production of protein by humic acid that ultimately increased the chlorophyll content. Humic substances and PGPR affected leaf chlorophyll content and photosynthetic ability and Ekin (2019) opined that the mode of action of both might partially be attributed to the N-

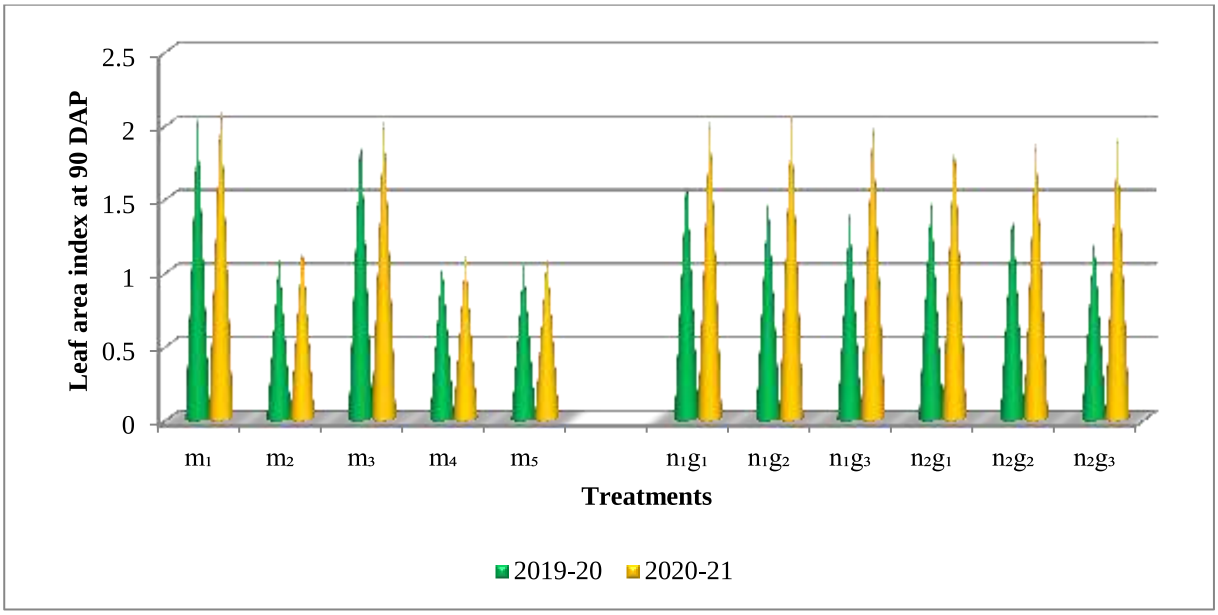


Fig.11a. Effect of method of planting and nutrient management x growth promoters on leaf area index at 90 DAP

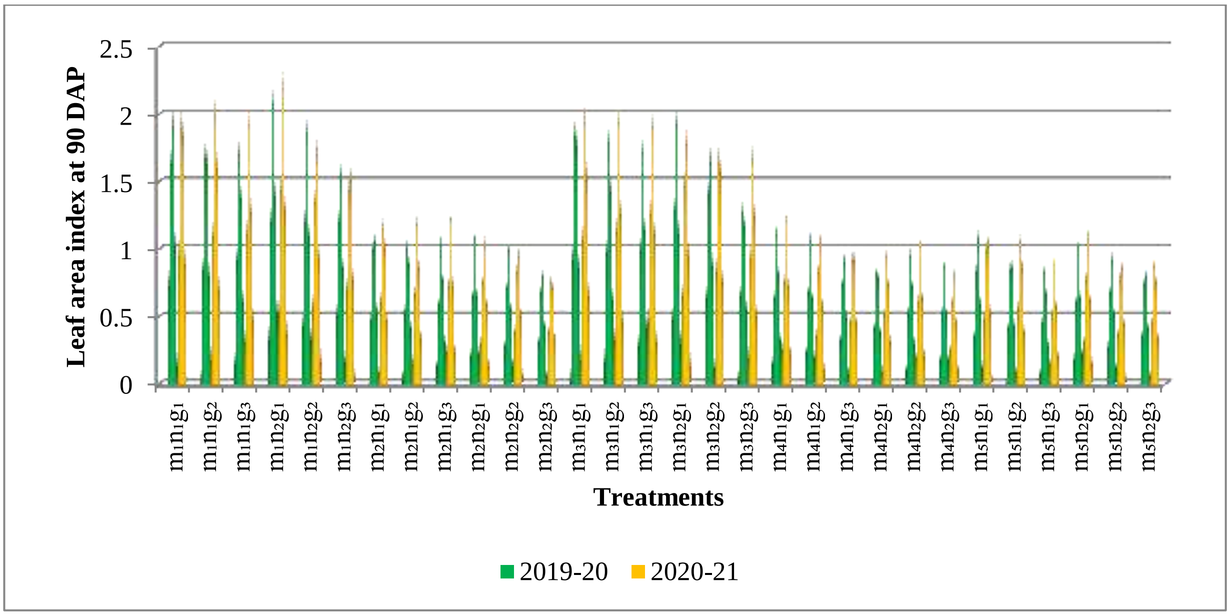


Fig.11b. Interaction effect of method of planting x nutrient management + growth promoters on leaf area index at 90 DAP

uptake/assimilation and IAA-like growth-regulating phytohormone activities. Improved growth and physiological processes with the inclusion of PGPR and humic acid in the management practice of Chinese potato thus resulted in increased values of the growth indices *viz*., CGR, RGR and NAR.

The higher harvest index in the wider spacing irrespective of the land configuration, is reasoned to be due to the greater partitioning of assimilates to tubers as a result of efficient use of resources and the effect of treatments on physical, chemical and biological properties of soil. However the interaction effects on harvest index remained comparable.

Senescence in plant tissues is accompanied by changes in membrane permeability (Rajinder *et al*., 1981). The phenological stages in crops involve a series of events concerned with cellular disassembly, and correlative influences play an important role in leaf senescence (Thomas and Stoddart, 1975; Thimann, 1980). Cytokinin application in plants results in enhanced cell division and shoot initiation (Jha and Saraf, 2015) by influencing their physiological and developmental mechanisms.

Benzyl adenine is a modified cytokinin and regarded as an anti senescent (Parmar *et al*., 2021). The role of BA in the promotion of leaf growth, inhibition of leaf senescence and preservation of chlorophyll has been described earlier. The delay in senescence in the treatment combinations involving BA (g_2) may be attributed to the above reason. Other physiological processes such as nutritional signaling and expansion of leaf are also greatly influenced by cytokinins (Wong *et al*., 2015) which have a bearing on the retention of leaf greenness and initiation of senescence.

Interaction effect revealed the superiority of bed method of planting at 30 cm x 15 cm spacing with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid ($m_1n_1g_1$) on physiological attributes like DMP, CGR and LAI, whereas the significantly highest NAR was recorded for the wider spacing

($m_2n_1g_1$) on account of it being negatively correlated with LAI. The variations in LAI are illustrated in Fig. 11b.

The biomass accumulation varied significantly with the main and subplot treatments during both the years. As expected in tuber crops, the maximum accumulation was seen in tubers (56.61-76.42 %) followed by stem (15.85-38.19 %) and leaves (5.79-8.28 %), accounting for the partitioning in the crop. The principles of fertilization in agricultural crops are oriented not only to source efficiency but also to sink productivity (Venkateswarlu and Visperas, 1987).The total photosynthesis is extremely dependent on leaf area. A high source activity and low sink capacity (temperate climates) and *vice versa* (tropical and subtropical climates) limits the yield. Hence a balance between source and sink becomes a pre-requisite. According to Evans (1989), this balance is achieved by adjusting either the capacity of leaf production (source) or the capacity of utilization of photosynthates by the growing tissues (sinks). The partitioning of photoassimilates from the source to the sink depends on many factors, photosynthetic capacity, environmental stress, nutrient availability, *etc*. (Paul *et al.*, 2017). Growth promoters when applied can curtail excessive vegetative growth, to improve photosynthetic efficiency and improve source-sink relationship (Deol *et al.*, 2018).

In the present work, significantly higher stem biomass was observed in ridge method of planting at 30 cm x 15 cm spacing (m_3) and was on par with m_1. This might be attributed to the increased plant height in the closely spaced plants. Ridge method of planting at a spacing of 30 cm x 30 cm (m_4) produced significantly increased leaf and tuber biomass and was on par with m_2. Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) proved superior in tuber biomass. Spitters (1987) indicated that tuber yield is determined by the fraction of total biomass that is partitioned to the tuber. Translocation of assimilates was lower for leaves and stems, and highest for tubers in potato (Geremew *et al.*, 2007).

Researchers (Potter and Jones, 1977; Meyer and Green, 1980) reported linear relationship between leaf area and biomass accumulation. The better translocation to the enhanced sink capacity was assured with the humic acid application . The positive influence of the bed/ ridge method of planting and wider spacing in conjunction with PGPR and humic acid could favourably modulate the source- sink balance in Chinese potato.

The growth hormones released or synthesized by the microbes in PGPR might have accelerated mobility of photosynthates from the source to the sink (Desai and Thirumala, 2014). Increasing the rate of photosynthesis with the enhancement of the source strength leads to better dry matter partitioning to the sink. Humic acid in this study showed a greater effect on the growth of roots than on shoots indicating a probably greater recourse allocation toward the roots. This is in agreement with the results of Adani *et al*. (1998), Atiyeh *et al*. (2002), and Turkmen *et al*. (2004). The dry matter accumulation is a result of translocation system of proton co-transport. This might have been possible by better absorption of K (Sathiyaraj, 2017). Efficient use of resources, increased nutrient availability of essential nutrients resulted in the greater partitioning of assimilates to tubers as a result of effects of inputs used in treatments on physical, chemical and biological properties of soil, which was higher in the second year, particularly under the influence of higher rainfall. The split application of chemical fertilizers and PGPR Mix 1 would have resulted in slower, extended availability of all essential nutrients leading to an efficient partitioning to tubers.

5.1.4 Quality Attributes of Tuber

Main plot as well as the interaction effect did not cause significant variations in the starch and protein content in both the years. But amongst the sub plot treatments, the combination of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) produced the significantly higher protein and starch content in both the years.

Potassium is believed to be the most critical nutrient for translocation of sugars and its higher dose (high soil status coupled with K fertilizer and solubilization) and availability stimulated more synthesis and allocation of starch to the roots favouring higher tuber yields. The N and P made available would have also enhanced the plant shoot and root growth that ensured better absorption and utilisation of the nutrients. Similar results on increased starch content with the PGPR Mix 1 were reported by Dhanya (2011) in sweet potato and Babu *et al.* (2020) in cassava.

The biological effect of humic acid includes induction of the genes encoding plastedial enzymes involved in Calvin cycle to produce glyceraldhyde-3-phosphate, which could be used to produce an array of different carbohydrate (El-Shabrawi *et al*., 2015). As documented by the authors, humic acid is reported to activate the enzymes adenosine diphosphate (ADP) glucose pyrophosphorylase which can couple adenosine monophosphate (AMP) to the phosphate of glucose-1-phosphate by removing pyrophosphate from adenosine triphosphate (ATP). This produces ADP-glucose, the substrate for starch synthase, which polymerizes it into starch. Alenazi *et al*. (2016) illustrated higher starch content in potato tubers with the application of humic acid.

Increased protein content might be due to the better nutrient availability, proper translocation of assimilates from source to sink, resulting in higher N uptake in Chinese potato. Since N is an integral part of protein and P is structural element of certain co-enzymes involved in protein synthesis, higher availability and uptake of N and P under integrated application of organics and inorganics along with biofertilizer resulted in higher protein content (Kachot *et al*., 2001). Further the N fixation due to PGPR inoculation, as per the reports of Stefan *et al*. (2013), also contributed to the stimulation of protein bio synthesis. The results are line in with those reported by Babu *et al.* (2020) in cassava and Yasmin *et al.* (2020) in sweet potato.

Sucrose content of tuber remained comparable with treatments imposed in both the years under study.

5.1.5 Plant Analysis

Nutrient uptake is a function of nutrient content and dry matter production. During both the years, bed method of planting with narrow spacing 30 cm x 15 cm (m_1) recorded significantly the highest N, P and K uptake. The effect of methods of planting on K uptake is illustrated in Fig. 12a. The higher dry matter production (Table 10a and 10 b) ensured increased nutrient uptake and hence better yields. With respect to the sub plot effects, the significantly highest N, P and K uptake were observed in the combination, 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) during both the years. Augmenting the microbiome and the related rhizospheric processes with PGPR application would have helped in the increased nutrient availability in biofertilizer inoculated treatment and hence enhanced uptake. Increased N and P fertilizer use efficiency when applied along with PGPR strains resulted in higher N and P uptake (Saber *et al*., 2012; Sood *et al*., 2018). The results of the present study conform to the increased P uptake reported in sweet potato (Dhanya, 2011) and N, P and K uptake in Chinese potato (Jayapal, 2012).

Humic acid application has beneficial effects on uptake of N, P and K (Fagbenro and Agboola, 1993; Radwan *et al*., 2011). Foliar spray of humic acid enhanced nutrient uptake, plant growth and yield in various crops : wheat (Delfine *et al*., 2005) and onion (Sangeetha and Singaram, 2007). In sweet potato, (El-Deen *et al.*, 2011) observed that the foliar spray of 0.5 per cent humic acid resulted in higher contents of N, P and K compared to that without its application. According to Shah *et al*. (2016), the application of chemical fertilizer and humic acid at 0.03 per cent in potato resulted in higher N and P content.

The highest K uptake (Fig. 12b) in $m_1n_1g_1$ corroborates the findings of Sathiyaraj (2017) who observed higher K uptake with the combined application of

100 per cent of RDF + FYM + biofertilizer with humic acid 0.1 per cent foliar spray in medicinal coleus.

5.1.6 Soil Analysis

Soil pH and soil organic carbon did not vary significantly with either the methods of planting or the combination of nutrient management and growth promoter in both the years, whereas significant variations were recorded in available NPK status. During both the years, available N, P and K status were the highest in mound method of planting at 30 cm x 30 cm (m_5) spacing and was on par with ridge (m_4) and bed method (m_2) of planting with wider spacing. Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 (n_1)+ humic acid recorded higher available N in both the years while the combination of n_1g_3 recorded the highest P and K status on par with n_1g_1 and n_1g_2 in both the years.

Method of planting has distinctive effects on the soil micro-ecological environment as well as soil quality (Qin *et al*., 2016). The plots with lower plant population (1,11,111 per ha in m_2, m_4 and m_5) recorded higher available nutrients. This might be due to the lower DMP suggesting a reduced nutrient uptake in these plots compared to plots with higher plant population, 2,22,222 in one hectare in treatments, m_1 and m_3. The results agree to the findings of Kalaichelvi (2008), Srikanth *et al.* (2009) and Shukla *et al*. (2014) who reported higher available nutrient status under wider spacing of plants.

Based on the observations it could be deduced that application of the biofertilizer consortium, PGPR Mix 1 heightened the rhizosphere microbiome and increased the nutrient availability. The microorganisms present in the PGPR Mix 1, include N fixers, P and K solubilisers which help in the mineralisation and solubilisation of nutrients in the soil through release of organic acids into the rhizosphere. The end result would be a modification of soil reaction and enhanced nutrient availability (Babu, 2020).

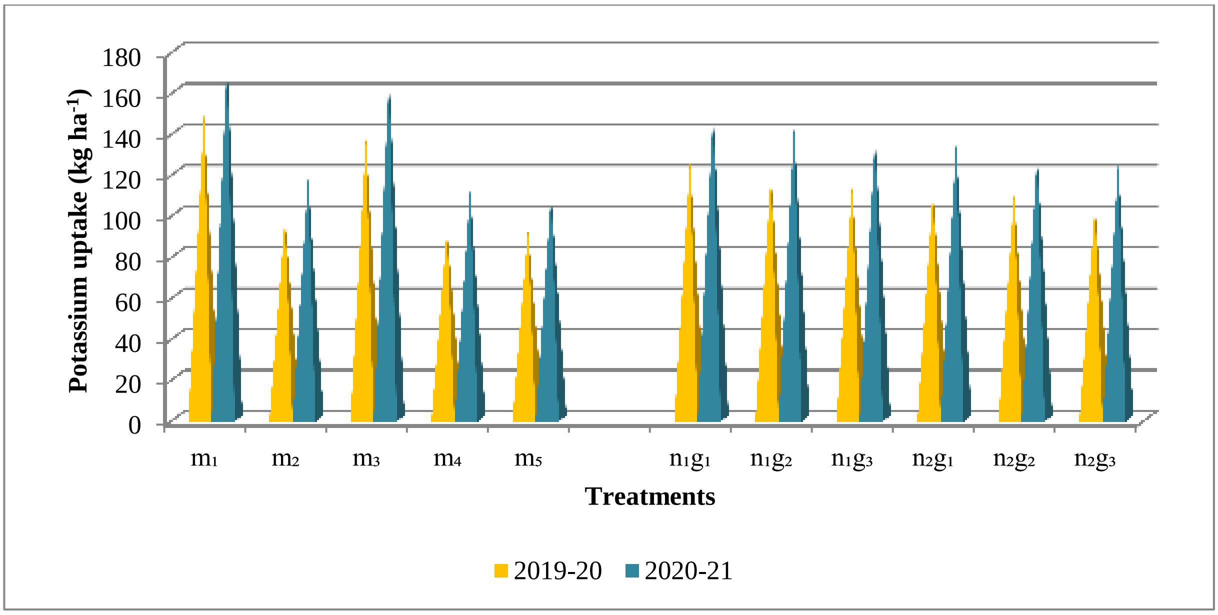


Fig.12a. Effect of method of planting and nutrient management x growth promoters on potassium uptake, kg ha^{-1}

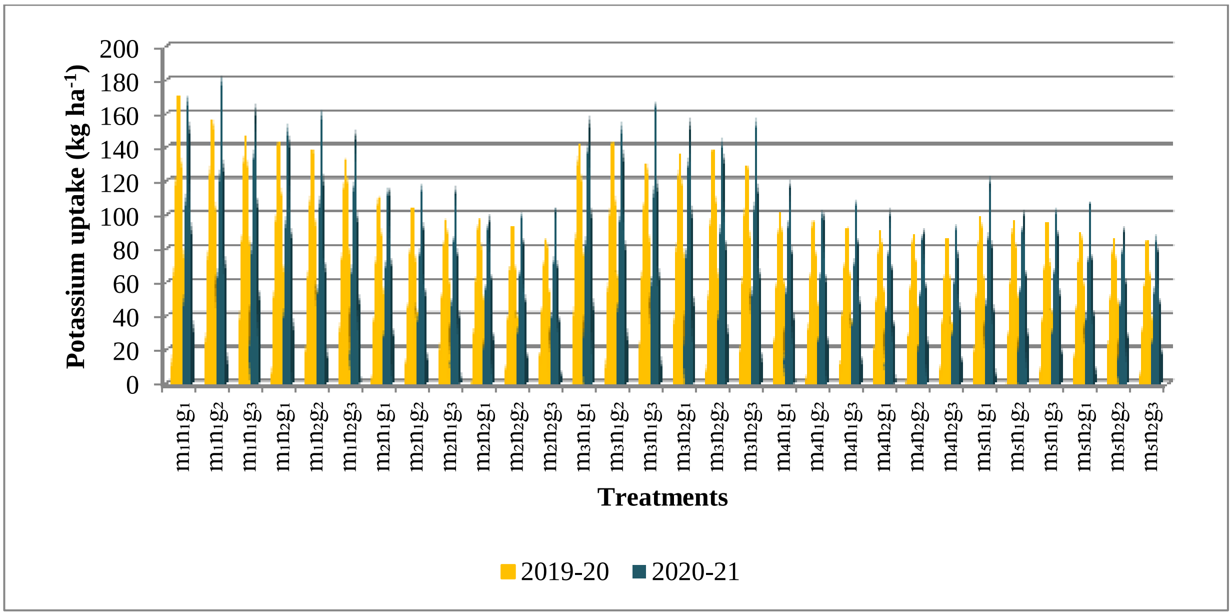


Fig.12b. Interaction effect of method of planting x nutrient management + growth promoters on potassium uptake, kg ha^{-1}

The increase in N status might be due to the fixation of atmospheric N by N fixers present in the PGPR Mix 1 which corroborates the results of Saharan and Nehra (2011).

The high initial P status in the soil along with the applied chemical fertilizers and solubilsation by *B. megaterium* in the PGPR Mix 1 would have led to the higher balance in soil even after uptake by Chinese potato plants. High efficiency of P solubilizers in releasing the soil P from insoluble sources has been reported by Meenakumari *et al*. (2008). The enhancement in P availability could be due to the production of enzymes (phosphatases), organic acids, protons, etc., by the P solubiliser present in the biofertilizer consortium (Miransari, 2013).

The inherent ability of the K solubiliser, *B. sporothermodurans* to release organic acids for the solubilisation could be the persuasive reason for higher available K in soil. Availability of K is affected by biological activities in the soil. Application of PGPR enhances the K availability by different mechanisms including acidolysis, chelation and oxidoreduction and thereby solubilizing K from minerals (Uroz *et al*., 2009).

Improved status of soil available P and K in coleus with the application of PGPR Mix 1 was also documented by Jayapal (2012).

Bacterial, fungal and actinomycete population enumerated in soil were higher in the bed method of planting at 30 cm x 15 cm spacing (m_1). Higher bacterial population in m_1 was on par with m_3 in both the years. The lowest count was in mound method of planting at 30 cm x 30 cm spacing (m_5) during both the years. Comparable microbial population were enumerated with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 irrespective of the growth promoters included in the treatments.

Land configuration to form beds, ridges and mounds loosened the soil and improved the porosity which would have had a strong impact on soil microbial community. Canto *et al*. (2020) opined that the pores in soil define regions with high microbial activity that is related to carbon turnover and sequestration. In addition it has been documented that raised bed planting optimizes water holding capacity and conductivity of soil solution, amplifying the bacterial counts *via* enhanced aeration/porosity of soil (Hemmat and Eskandari, 2004; Patino-Zúniga *et al*., 2009). Zhang *et al*. (2012) also reported higher population of bacteria, fungi and actinomycetes in raised bed planting and substantiated this with the improved physical properties associated with formation of raised beds. Nevertheless, the counts were higher with lower spacing of 30 cm x 15 cm in the modified methods of planting compared to the wider spacing. This may be attributed to the higher plant population and root density that arise with closer spacing. Plant roots play an active role in designing the soil and rhizospheric environment (Costa *et al*., 2006; Haichar *et al*., 2012) and the root surface area determines the extension of the rhizosphere effect (Dotaniya and Meena, 2015). The roots release a variety of organic compounds that are responsible for enhancing microorganism population in rhizosphere zone due to increased availability of carbon for food and energy (Aira *et al*., 2010). Bowen and Rovira (1999) have documented that plants secrete nearly 10-30 per cent of the photosynthates through the root system into the rhizosphere soil. Photosynthates are comprised mainly of carbon compounds, electrons, protons, water, and inorganic ions, which all enter the rhizosphere as root exudates (Olanrewaju *et al*., 2019). As these root exudates represent an easily degradable nutrient source for microorganisms allowing rapid proliferation, larger the root volume, higher will be the microbial population. Arguably this would be the plausible reason for the higher counts observed in closer spacing.

Comparing the microbial counts, population of bacteria was the highest followed by actinomycetes and fungi. Dotaniya and Meena (2015) reported that the rhizosphere effect is higher for bacteria > fungi > actinomycetes > protozoa. Irrespective of the growth promoters, all the treatments which involved an integrated nutrient (INM) package, 60:30:120 kg NPK ha^{-1} + biofertilizer, PGPR Mix 1, recorded the highest population of all microbes enumerated under study. The results corroborate the findings of Vijendrakumar *et al*. (2014) and Gopi *et al*.

(2020). According to Vijendrakumar *et al*. (2014), dual and triple inoculation of biofertilizers resulted in maximum counts in soil with respect to both beneficial and general microflora. Repeated applications of PGPR (3 times, basal, 30 DAP and 60 DAP) were done in the current study also. The lowest population of microbes was recorded in plots without PGPR Mix 1. It is validated that the N fixers, P and K solubilisers in the consortium biofertilizer also amplified the microbiome in the rhizosphere. In addition the better nutrient availability, uptake and hence the growth and photosynthetic efficiency with INM would resulted in proliferated root growth, exudation of organic substances that enhanced microbial activities.

In general, bacterial, fungal and actinomycets counts were significantly higher in the treatment combination involving a closer spacing and inoculation of PGPR Mix 1.

The higher microbial counts in bed method of planting (30 cm x 15 cm) with 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 is a reflection of the individual effects. The favourable environment for root and canopy spread would have enhanced the rhizodeposits and created a niche for microbial activity. The microbes help plants to grow and function more effectively by increasing plant pathogen resistance, retain more water, take up and utilize more nutrients and, in general, increase their growth (Olanrewaju *et al*., 2019). It has been reported that the microbiota vary with the root exudates and other rhizodeposits secreted by plants (Moe, 2013). C_3 and C_4 plants show variations in the types of exudates released into the rhizosphere, with C_3 plants are reported to exude more carbohydrates and organic carbons, (Nabais *et al*., 2011) and C_4 plants, higher numbers of organic acids and amino acids compared to C_3 plants. Coleus is a C_3 plant and microbes that have affinity for mannose, maltose, and ribose sugars are more prominent in its rhizosphere. The addition of PGPR Mix 1 also contributed to the increased microbial activity in the rhizosphere.

Markedly higher dehydrogenase activity was recorded in m_1 in both the years and was on par with m_3 in the second year. The combination of NPK with growth promoter also significantly influenced the dehydrogenase activity in both the years of experimentation. The treatment n_1g_1 recorded superior values of dehydrogenase activity in both the years and were on par with n_1g_3 in the first year and with n_1g_2 and n_1g_3 in the second year. Among the treatment combinations, $m_1n_1g_2$ recorded the highest value in the first year and $m_1n_1g_1$ in the second year.

The activity of the enzyme dehydrogenase in an organism or tissue serve as an index of the metabolic activity. Substrate specific dehydrogenases function as oxido-reducto enzymes transferring electrons from one substrate to the other (Priya and Kumutha, 2013). Thus the dehydrogenase serve as a source for more electron generation and hence, more energy for the tissue. Higher plant and root density by virtue of its increased root activity and enhanced rhizodeposits in the soil promote microbial growth and hence dehydrogenase activity in the soil. Increased activity with biofertilizer inoculation might have triggered dehydrogenase activity directly or indirectly by enhancing the rhizosphere microorganisms.

5.1.7 Economic Analysis

Among the various treatment combinations tried, bed method of planting at 30 cm x 15 cm spacing along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid ($m_1 n_1g_1$) was found to be the most profitable recording higher values of net returns and BCR in both the years (₹ 625639 ha^{-1} and 3.72 in the first year and ₹ 676953 ha^{-1} and 3.95 in the second year respectively). It could be attributed to the significantly highest tuber yield obtained in the treatment due to the cumulative effect of higher plant density and balanced nutrient management practice involving PGPR Mix 1 and humic acid as growth promoter. Pooled mean yields of treatment combinations also recorded the highest value of net returns and BCR in $m_1 n_1g_1$ (Fig. 13 and 14). Schultheis *et al.* (1999) reported

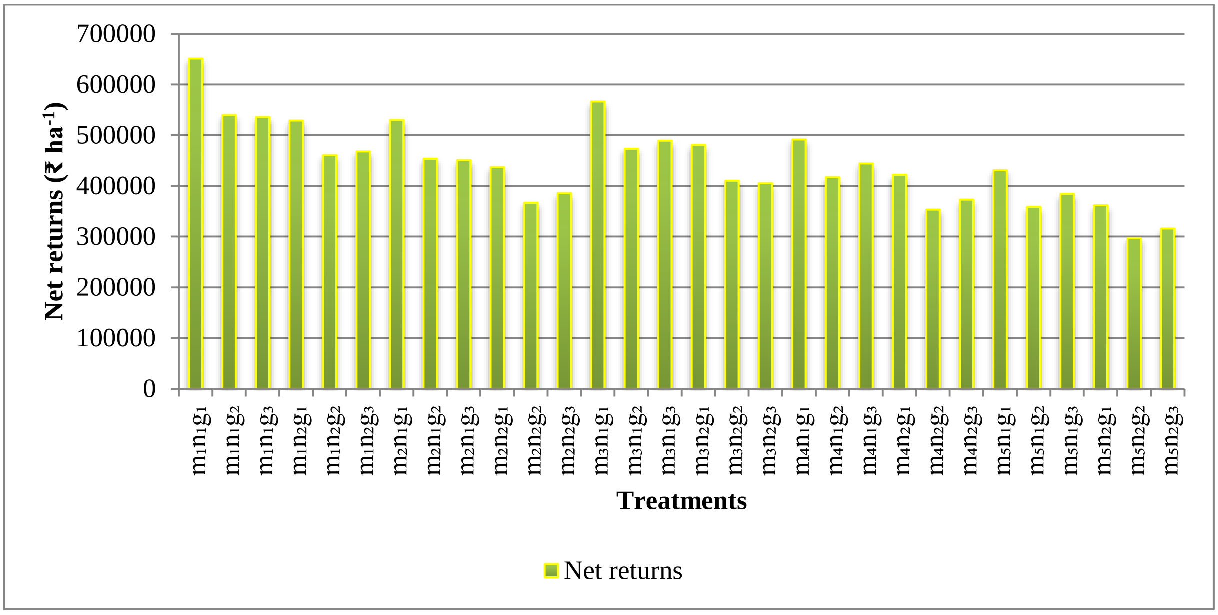


Fig.13. Effect of method of planting x nutrient management + growth promoters on net returns (mean), ₹ ha^{-1}

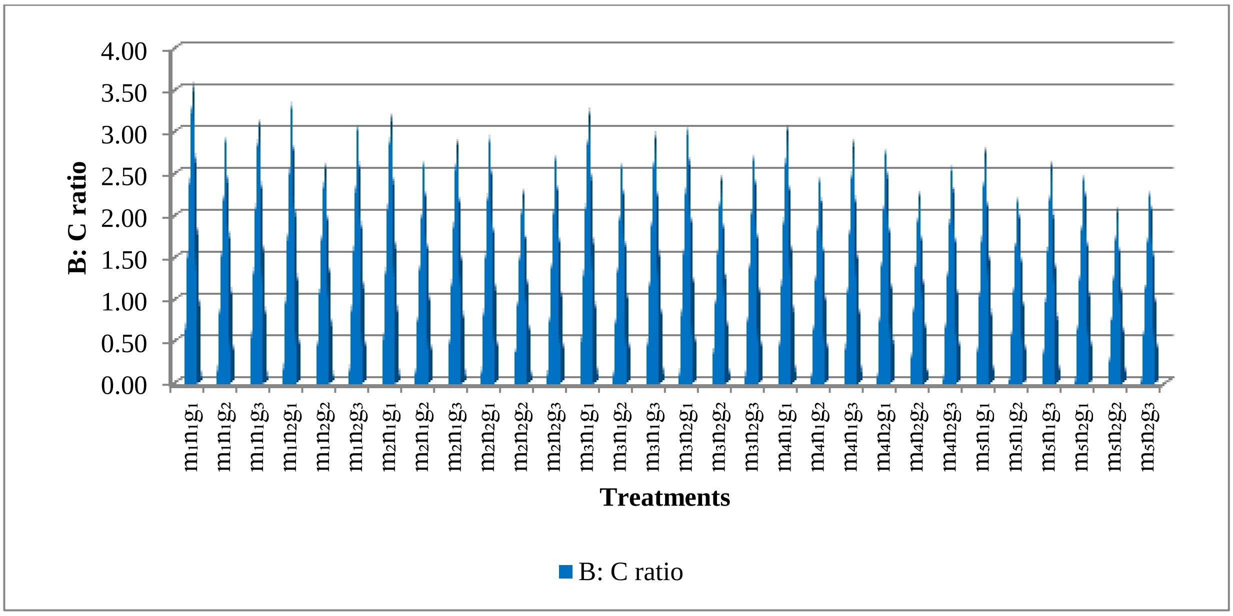


Fig.14. Effect of method of planting x nutrient management + growth promoters on BCR (mean)

higher net returns in sweet potato with narrow intra row spacing (15 cm). Higher net income and BCR were recorded with application of biofertilizer in coleus (Jayapal, 2012) and in medicinal coleus (Ravikumar *et al.*, 2013).

The results of the research work revealed the most suitable combination in Chinese potato for increased marketable tuber yield, net returns and B: C ratio to include planting of the cuttings on beds at 30 cm x 15 cm spacing along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 @ 2 per cent, 5 g per plant thrice, at basal, 30 and 60 DAP + and spraying humic acid @ 5 g L^{-1} twice, at 45 and 75 DAP.

5.2 EXPERIMENT II: INFLUENCE OF CARBON DIOXIDE FERTILIZATION ON GROWTH, YIELD AND TUBER QUALITY IN CHINESE POTATO

Plant growth is affected by many environmental factors, including ambient atmospheric conditions (e.g. temperature, light, humidity and CO_2 concentration) and soil parameters (e.g. pH, viscosity, water and nutrients status) (Chang and Zhu, 2017). Carbon dioxide is an essential environmental resource required as a raw material for the orderly development of all green plants. It forms the basic input for the fundamental physiological activity, photosynthesis, the driving force of life on earth.

Rising CO_2 concentrations are likely to have profound direct effects on the growth, physiology and chemistry of plants, independent of any effects on climate (Ziska, 2008). Elevated CO_2 will increase the photosynthetic rate in plants (Fernandez *et al*., 2002) and hence in the present study, the response of Chinese potato to increased CO_2 was assessed by using a trench system with different organic materials as substrates for CO_2 evolution. In order to trap the CO_2 released by dark respiration and soil respiration the trenches were covered with dome shaped frames of uv stabilized sheet, daily from 4 pm to 10.30 am. The substrates were spread at the base and allowed to decompose.

5.2.1 CO_2 Evolution

A critical appraisal of the CO_2 evolved from the different substrates used (Fig. 15a and b) revealed the trend of release: it was comparatively higher immediately after application, up to two weeks, indicating the rapid decay in the initial days, but then on declined. The maximum release from the substrates, cow dung + coir pith in 2:1 ratio with and without the decomposer *Pleurotus* occurred in the second week after application. Towards the later stages of the crop, the quantum of CO_2 evolved from all the substrates remained almost similar in both the experimental period. Similar reports of higher initial CO_2 release and a slower evolution during the rest of incubation period have been documented (Abro *et al*., 2011; Minu, 2015; Navale, 2014; Laharia *et al*., 2020).

Green plants and photo- and chemoautotrophic microbes transfer carbon from the atmosphere to soil *via* ‘carbon-fixing’ process of photosynthesis converting them into organic compounds. The reverse route that includes decomposition of organic material by ‘organic carbon-consuming’ heterotrophic microorganisms which utilise the carbon of either plant, animal or microbial origin as a substrate for metabolism, retaining some carbon in their biomass and releasing the rest as metabolites or as CO_2 back to the atmosphere, is also functional (Liang and Basler, 2011). Zhu *et al*. (2020) abstracted that the release of CO_2 into the atmosphere with organic matter decomposition largely resulted from the activities of microorganisms and macrofauna present in the soil.

Alexander (1977) had documented that under aerobic conditions, approximately 20-40 per cent of the substrate C is assimilated by microorganisms and the rest is released as CO_2. In the present study, coir pith, cow dung solely and amended with the fungal decomposer *Pleurotus* and nutrients, N and P, were used as the substrates for CO_2 evolution. The degradation of coir pith was accelerated with the addition of cow dung as evinced by a higher CO_2 release compared to coir pith alone, but maximum CO_2 evolution was recorded with the addition of *Pleurotus* and a source of N and P along with cow dung.

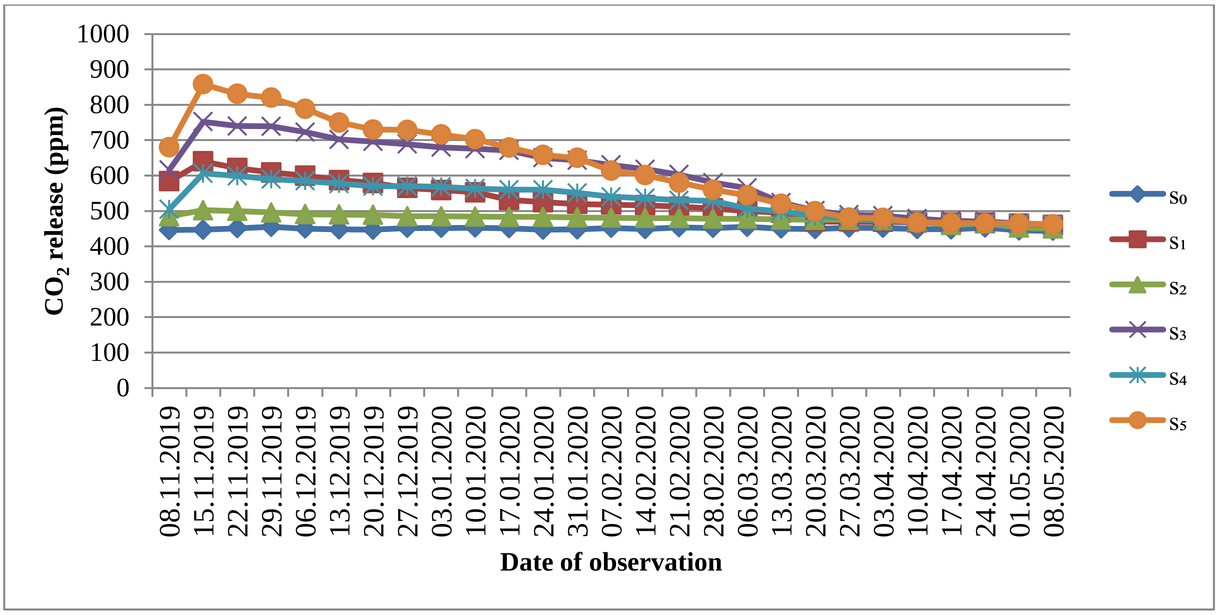


Fig.15a. CO_2 release in trenches from the different substrates at weekly intervals (2019-20), ppm

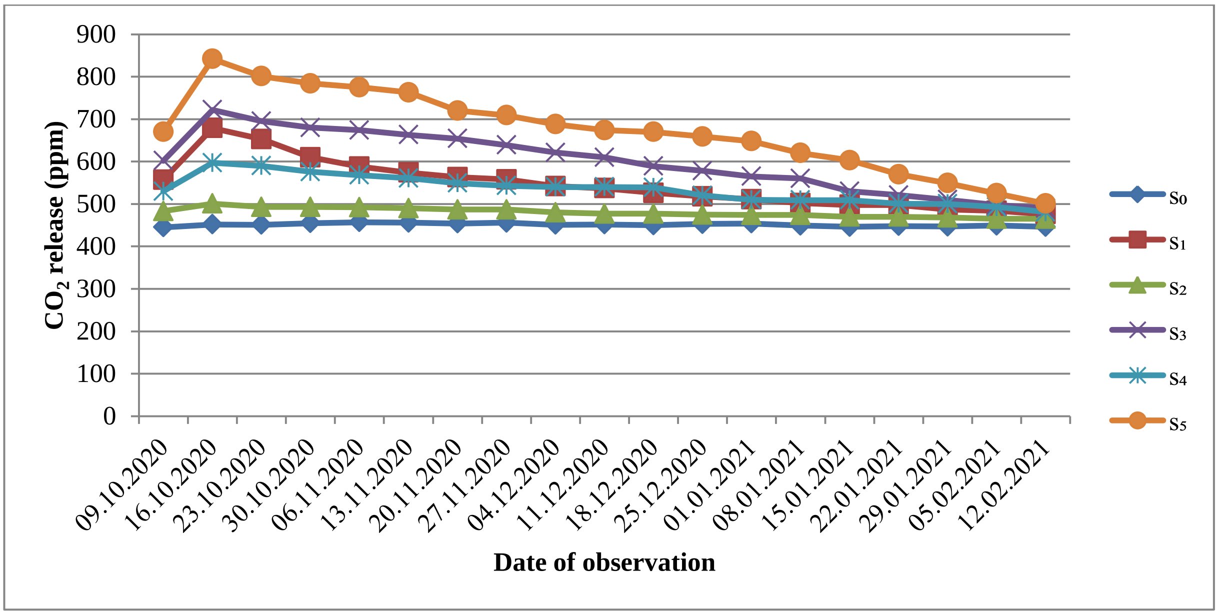


Fig. 15b. CO_2 release in trenches from the different substrates at weekly intervals (2020-21), ppm

Jothimani *et al*. (1997) observed higher evolution of CO_2 from coir pith when inoculated with microbes compared to urea and rock phosphate addition emphasizing the significance of microbes in accelerating decay. The nutrient addition would also have favoured the activity of microorganisms and hence the CO_2 release. It is also inferred that the extra carbon made available with the addition of cow dung might have resulted in more carbon in the decaying system (Amlan and Devi, 2001).

Cow dung harbours a diverse group of microorganisms which can enhance the decomposition process. Kumar and Ganesh (2012) enumerated the bacterial, fungal and actinomycete population in coir pith as 6.5×10^6, 5.12×10^5 and 2.27×10^4 cfu g^{-1} respectively. In cow dung, the viable bacterial and fungal count were in the range of 1.5×10^7 to 5.8×10^8 cfu g^{-1} and 1.0×10^7 to 8.0×10^8 cfu g^{-1}, respectively (Munshi *et al*., 2018) clearly illustrating the higher microbial activity and substantiating the higher CO_2 release in cow dung included substrates.

Carbon : N ratio is widely acclaimed as a primary decomposition parameter (Wang *et al*., 2009) that influences the rate at which a residue decomposes and the amount of N recycled from the residue (Boyd, 2009). Carbon and N contents of organic materials influence microbial decomposition (Rahman, 2013), and thus release of CO_2 depends on C: N ratios of organic materials applied to soil also. Analysis of the C: N ratio of the substrates revealed wider C: N ratio (70.1: 1 in the first year and 60.5: 1 in the second year) in coir pith used (Table 37) endorsing the lowered quantum of CO_2 release. Literature cited reveal nearly 37 per cent lignin in coir pith (Thomas *et al*., 2013), another factor slowing down the decomposition. Mixing coir pith with cow dung in 2:1 lowered the ratio to 46.8: 1 and 42.4: 1 in the first and second year respectively, on account of the augmented N content. This would have facilitated the decomposition process. The C: N ratio was the lowest in the substrate containing cow dung and coir pith with *Pleurotus,* N and P additions (10.3 and 11.0).

Monitoring the air and soil temperature in the trenches at weekly intervals, it was observed that the temperatures were higher within the trenches compared to the open/ ambient condition (Tables 27a, 27b, 28a and 28b). The trenches were kept closed for 18 ½ h daily, as a result of which the CO_2 released was trapped within and caused its built-up in the crop microclimate. Carbon dioxide accumulation amounted to 858 and 842 ppm (first and second year), the highest in s_5 followed by s_3 during the first two weeks. It is conjectured that the rise in temperature consequent to the increased CO_2 concentration influenced the crop growth in the trenches. The high temperature and poor wind movement coupled with the humidity inside might have greatly influenced the growth and yield performance of Chinese potato.

5.2.2 Growth Attributes

Carbon dioxide (CO_2) fertilization significantly influenced the growth attributes in Chinese potato in comparison to plants with no substrate application in both the years of experimentation. The canopy development was enhanced, plants were greener and grew luxuriantly in the CO_2 fertilized treatments and the growth attributes were the lowest in the treatment of no substrate addition. The positive effect perceived was the manifestation of increased rates of photosynthesis under increased CO_2 conditions. This accords to the reports of Yubi *et al*. (2021) in potato and Ruiz-Vera *et al*. (2021) in cassava.

It was also noted that Chinese potato planted either directly in the trenches or in grow bags placed in the trenches did not differ in their response to the increased CO_2 evolved with respect to the substrates due to the difference in the years of cultivation (2019-20 and 2020-21). The microclimate created within was thus solely responsible for the crop behaviour. The substrate in which cow dung was added to coir pith along with the decomposer enhancers (*Pleurotus* and nutrients) resulted in a quantum of CO_2 release that was responsible for improved growth attributes.

It is surmised that the increased growth was due to the additional photosynthates made available at the higher CO_2 concentration (Bhattacharya *et al.*, 1985). Elevated CO_2 can accelerate photosynthesis as the carboxylation rate of RuBisCo is increased and the oxygenation of ribulose-1, 5- bisphosphate is competitively inhibited (Drake *et al.*, 1997). Previous studies also assigned the stimulation in growth attributes to a higher photosynthetic rate (Ainsworth and Long, 2005) and lower photorespiration (Booker *et al*., 2007).

Carbon dioxide influences several developmental processes like leaf initiation and expansion and branch development which are finally reflected in the leaf area (Ackerly *et al*., 1992). According to Pritchard *et al*. (1999), increased cell expansion, epidermal cells per leaf and mesophyll area contributed to the increased leaf area. The results on the higher leaf area obtained in the present study are supported by the works of Kumari *et al*. (2013), which illustrated that eCO_2 supported more photosynthates for leaf expansion in *Beta vulgaris* and Zaher *et al*. (2021), who reported significantly higher number of leaves and leaf area in taro plants with an exposure to eCO_2.

5.2.3 Yield attributes and yield

In the present study, tuber formation was not observed in both the years in the trench system of CO_2 fertilization. During the first year, excessive vegetative growth was elicited and the crop was retained for nearly 238 days, 98 to118 days more than the normal duration. The experiment was repeated in the second year during which the cuttings were planted in grow bags to take care of the temperature in soil at the base of the trench. Nevertheless, tuber induction and development did not happen.

Reports on increased tuber yields in potato under eCO_2 are available (Schapendonk *et al*., 2000). But, in the present study, the Chinese potato crop did not respond in a similar manner in both years during which the experiment was conducted. Enhanced vegetative growth was evident but the plants failed to produce tubers and a few roots were seen when uprooted at harvest (Plate. 4).

Moreover, tuberization was not recorded even in the treatment in which substrates for CO_2 evolution were not included.

An insight into the physiology of tuberization brought to focus the significant role of environmental factors that govern tuber induction and development in root crops apart from the genetic control. According to Posthumus (1973), the most important factors that influence tuberization are photoperiod, temperature, light (intensity and quality), mineral nutrition, water availability and viruses. Melis and van Staden (1984) opined that tuberization is the physiological process wherein a stem section or a root of a plant undergoes a morphological change to become a special storage organ, thereby altering radically the dry matter distribution pattern within the plant.

Perusal of the data on the CO_2 evolved in the no substrate added treatment (Table 27a and 27b) showed the CO_2 trapped within the trench to be in the range of 445 to 456 ppm. This was nearly 11.22 per cent higher than the ambient CO_2 reading of 410 ppm and an air temperature of 27.3°C, nearly 20.80 per cent higher than ambient air temperature. Thus it is deduced that the temperatures within the trenches had significant influence on tuberization.

A higher CO_2 build up is usually associated with an increase in temperature. Air and soil temperatures recorded at 7.30 am in the trenches were 3 to 5.2°C higher than that in the open. Among the various environmental factors, temperature is one of the most important cues affecting tuberization in potato (Lafta and Lorenzen, 1995; Martinez-Garcia *et al*., 2001; Dutt *et al*., 2017).

High temperatures inhibit or delay tuberization in tuber crops (Melis and van Staden, 1984). There are reports of non expression of transported tuberization stimulus in potato at warm temperatures (Reynolds and Ewing, 1989) resulting in poor tuberization (Ewing and Struik, 1992). In potato, unfavourable conditions like high temperature and low light intensity inhibited tuberization and large amounts of assimilates were used for shoot growth. All the stages and phases of

Plates 4. Tuber development in CO_2 fertilization study and in open field

tuberization, *ie*., tuber induction, tuber set, tuber bulking, tuber number, size and yield have been found to be affected by temperature in potato (Dutt *et al*., 2017).

Documented literature on the physiology and cardinal temperatures in Chinese potato are very meagre, practically nil. Among tropical tuber crops, Chinese potato bears maximum analogy to sweet potato in growth habit and both being root tubers, the observations in the present experiment are validated with the research works in sweet potato.

Studies on the tropical root crop, sweet potato, revealed that any unfavourable or adverse condition shortly after transplanting resulted in pencil root production instead of the normal storage roots. The most important factors identified include soil moisture, air and soil temperature. An excess or deficit soil moisture condition had negative influence on tuber production. In the present study the crop was irrigated to maintain the soil moist, and irrigation was avoided whenever rains occurred, thus ruling out the chances of an unfavourable soil moisture hindering tuber formation, soil and air temperature assumed more importance. This is in agreement with the observation made by Loretan *et al*. (1994).

Ravi and Indira (1999) reported that storage root formation, enlargement and starch synthesis in sweet potato are enhanced with air temperature ranging from 14 to 22°C and adequate soil moisture. According to Gajanayake *et al.* (2015), the optimum temperatures for maximum stem, root, and leaf biomass yields in sweet potato were at 29.2, 25.6, and 26.7°C, respectively. Storage root fresh weight was the highest at temperatures ranging from 21 to 26°C and the storage root production efficiency declined from 32 to 4 per cent with an increase in temperature from 25/17 to 40/32°C, and biomass partitioning to the above ground biomass increased.

Ravi *et al*. (2009) stated that both air and soil temperature regulate the competition between shoot and storage root growth in sweet potato. In our study too it was evident that the air temperature and soil temperature in both the years irrespective of the CO_2 concentration (s_o) were higher in the trenches especially during 8th to 12th week of planting during which tuber initiation should have occurred in consonance with the open field crop wherein tuber initiation happened 50-55 DAP.

Reynolds and Ewing (1989) opined that high soil temperature can even eliminate tuber development as observed in potato. It was elaborated that the tuberization induction signal from the leaves gets affected by the air temperature while the tuberization expression signal from the leaves can be blocked by high soil temperatures. In addition, under higher than optimum temperature conditions a shift in assimilate allocation favouring the shoots can also occur leading to decreased tuber growth (Gajanayake *et al.*, 2015).

The process of tuberization and assimilate partitioning are inseparable and controlled by endogenous hormones. Changes in environmental conditions such as temperature, photoperiod and light intensity can influence the levels of the endogenous plant growth hormones (Jackson, 1999).

Giberillins inhibit and abscisic acid promotes tuber induction. Auxins and cytokinins influence the tuber size whereas ethylene inhibits tuber induction *in vivo* or may cause swellings of stolons without starch (Mingo-Castel *et al.*, 1976). It was also reported that there exists an inverse relationship between vegetative and tuber growth in root crops wherein the factors that promote vegetative growth inhibit tuber growth. Tuberization involves a switch in the pathway of assimilate unloading (Viola *et al.*, 2001). Based on their experiments in potato, Roumeliotis *et al.* (2012) postulated that stolon tip swelling requires a decrease in active gibberellic acid (GA) content. Auxin content at the swelling sites of the stolons exhibited a several fold increase prior to tuber swelling and the genes involved in GA degradation, an upregulated profile at this stage. Similar reports of the inhibitory role of GA in tuber induction were documented earlier (Menzel, 1980; Ewing, 1987; Corsini *et al.*, 1989; Xu *et al.*, 1998).

High temperature increases the gibberellin levels (Railton and Wareing, 1973; Menzel, 1980) and the poor tuberization in the present experiment can as well be ascribed to the above mentioned influence of GA. It is also speculated that gibberellins are involved in carbohydrate metabolism and in the leaves, carbohydrates are proportioned for shoot growth (Melis and van Staden, 1984). Further as reported by Opaleye *et al*. (2018), there exists a lack of balance between the source potential and sink capacity in Chinese potato and this became more pronounced with the enrichment of CO_2. The increased vegetative growth stipulated high photosynthate production but the phloem source to sink (tuber) transport seemed inhibited. Thus it is interpreted that the eCO_2 coupled with the modified microclimate within the trench influenced the crop phenology and would have caused non tuberization in Chinese potato.

5.2.4 Physiological Attributes

Chlorophyll content in the leaves was significantly higher in cow dung + coir pith (2:1) substrate (s_3) at 45 DAP. While the treatment s_5 (s_3 + *Pleurotus* 1g kg^{-1} + N + P @ 2% w/w) registered higher contents at 90 DAP in both years (Fig. 16a and b). The stages coincided with the period during which maximum CO_2 was released (Tables 27a and 27b) and the effects were expressed in the plants. Nevertheless, as growth progressed, CO_2 release declined and the amounts remained comparable from the 20th week onwards with slightly higher values than the no substrate treatment. Scrutiny of the data on CO_2 evolution indicated that CO_2 released towards the later stages remained similar in the substrate applied trenches as that without any substrate application

Higher chlorophyll content could be related to the RuBisCo production (Wilkins *et al*., 1993) and is suggested to be an adaptation of the plants under eCO_2 to increase the photosynthetic activity (Bhatt *et al*., 2010). Increase in the chlorophyll content under eCO_2 has been reported in soybean (Li and Gupta, 1993) and in sugar beet (Manderscheid *et al*., 2010).

In the CO_2 fertilisation study in the trenches, the crop duration was extended beyond the normal duration of 120-140 days for the Suphala variety during the first year, but without tuberization. Hence the experiment was repeated in the second year, however despite the open field crops completing its cropping period with tuber bulking and being harvested at 140 and 143 DAP in the first and second year, the plants in the trenches did not produce tubers even when maintained for a longer period.

Comparing the days taken by the plants to reach the senescence stage in response to the substrates and CO_2 evolved, it was observed that the plants grown without CO_2 fertilization (no substrate) took more number of days for initiation of senescence *viz*., 223 days in the first year and 125.7 days in the second year, nearly 3.38 and 6.52 per cent higher than in the maximum CO_2 evolved treatments. Accelerated senescence with eCO_2 was documented in sweet potato (Bhattacharya *et al*., 1985) and in potato (Kimbal *et al*., 2002). Ludewig and Sonnewald (2000) have reasoned that the production of more ethylene under elevated CO_2 conditions resulted in the accelerated senescence compared to non CO_2 fertilized plants.

Biomass partitioning indicate the allocation followed the order, stem > leaf > roots/tubers irrespective of the treatments included (Fig. 17a and b). The treatment cow dung + coir pith (2:1) and (s_3) + *Pleurotus* + N + P (s_5) recorded the significantly highest biomass (stem, leaf and root) accumulation per plant during both the years of experimentation and it remained the lowest when grown without substrate application.

According to Menzel (1985), stem weight was greater at higher temperatures with low irradiance, and diversion of plant dry matter to the tubers fell to less than 5 per cent. The significant influence of high temperatures on the partitioning of photosynthates between shoots and tubers was illustrated (Wolf *et al*., 1990). According to the authors, the optimum temperature for shoot growth differs from that for tuber growth and increased temperature enhances partitioning

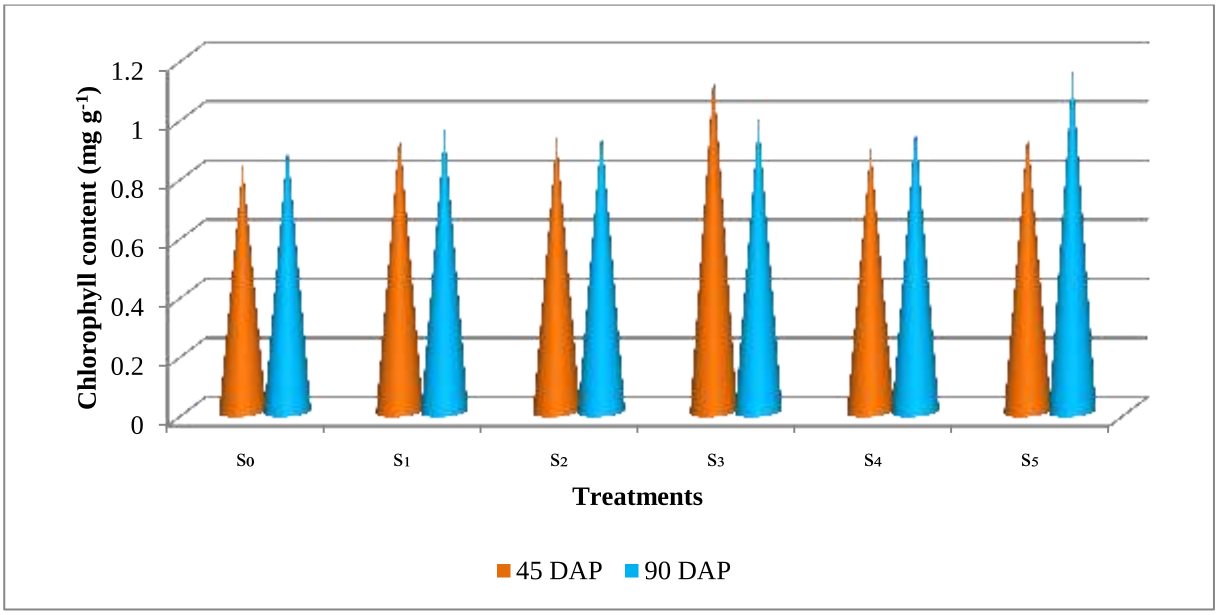


Fig. 16a. Effect of CO_2 fertilization on chlorophyll content at 45 and 90 DAP (2019-20), mg g^{-1}

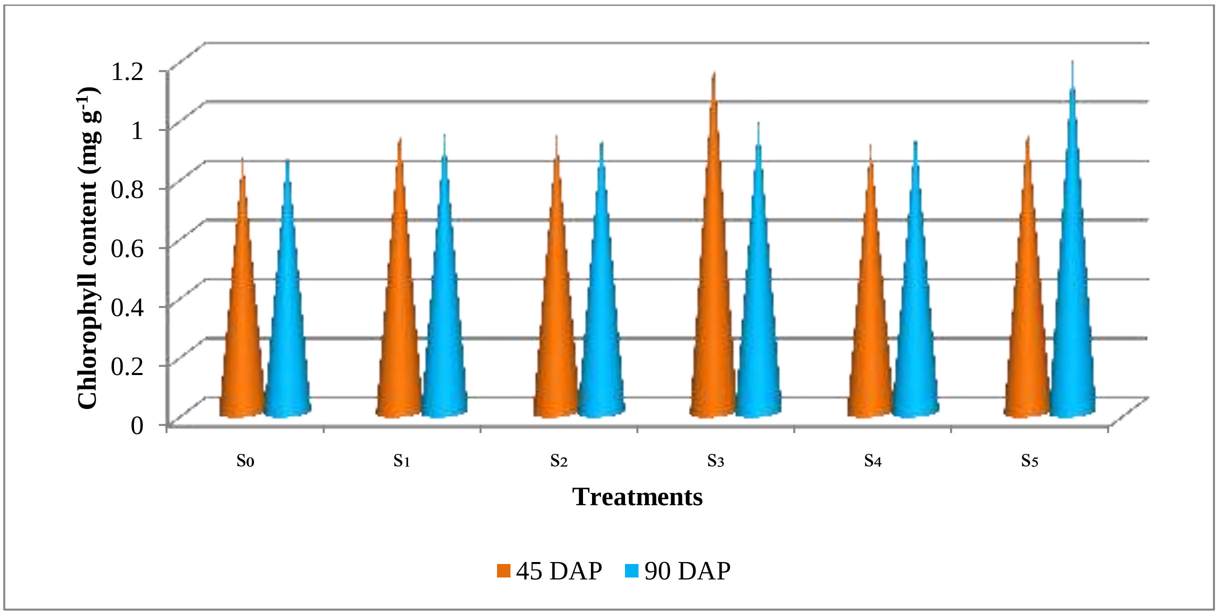


Fig. 16b. Effect of CO_2 fertilization on chlorophyll content at 45 and 90 DAP (2020-21), mg g^{-1}

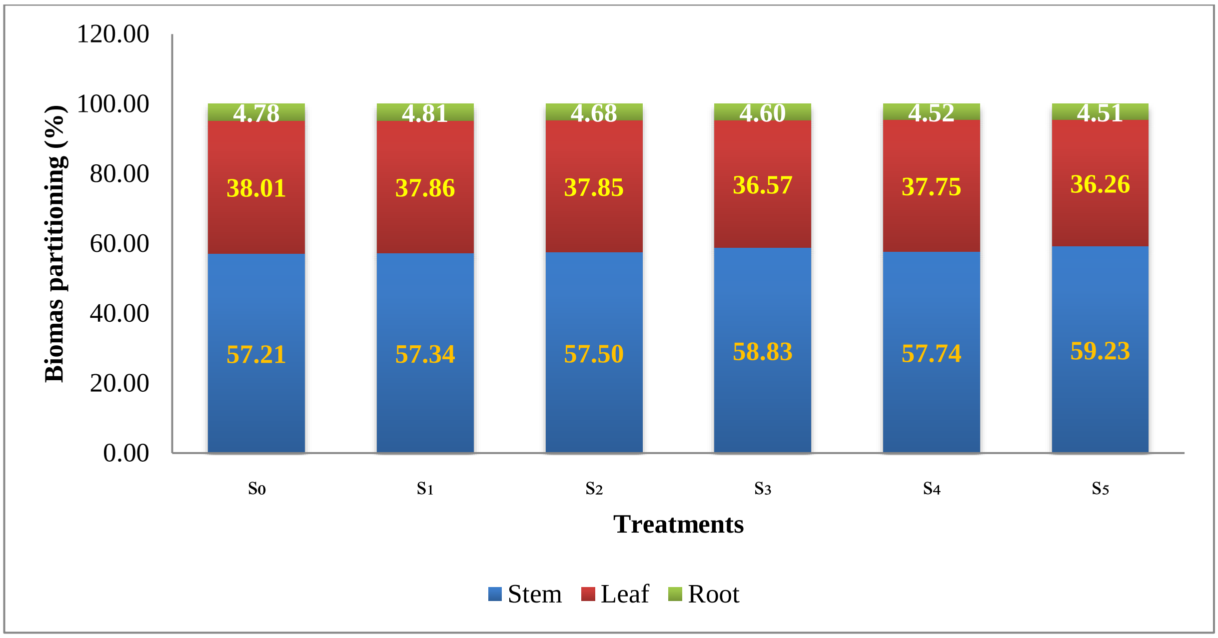


Fig. 17a. Effect of CO_2 fertilization on percentage biomass partitioning (2019-20)

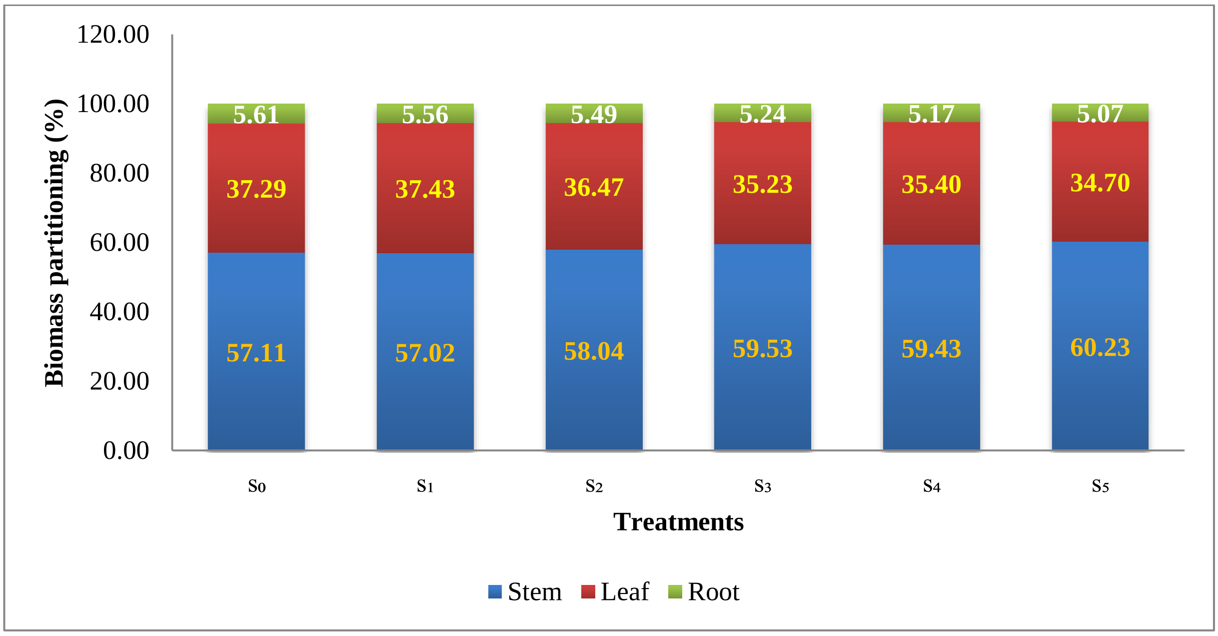


Fig. 17b. Effect of CO_2 fertilization on percentage biomass partitioning (2020-21)

to shoots. This is supported by Dutt *et al*. (2017) who also documented higher diversion to shoots rather than tubers at higher temperatures. Elevated day and night (29°/27°C) temperatures impaired photosynthesis and assimilate production in potato (Hastilestari *et al*., 2018) and consequently biomass allocation shifted away from tubers towards leaves indicating reduced sink strength of developing tubers.

In the present study the increased number of branches, leaves, and leaf area (Tables 31, 32 and 33) contributed towards higher shoot biomass compared with no substrate and open crop. Earlier research had shown that biomass response to atmospheric CO_2 enrichment is generally greater for plants with a C_3 (33-40 % higher) compared to the 10-15 per cent increase in C_4 photosynthetic pathway (Prior *et al*., 2003).

Increased dry matter production and biomass with elevated CO_2 observed accords that in sweet potato (Runion *et al*., 2018) Saminathan *et al*., 2019), in potato (Aien *et al*., 2014) and in taro (Zaher *et al*., 2021). On the contrary, the greater partitioning to tubers (Bhattacharya *et al*., 1985) or increased root dry weight (Runion *et al*., 2018) as recorded in sweet potato were not observed in the present study.

An observation noted is that even without the evolution of CO_2 in the no substrate treatment, biomass allocation to the roots remained lower indicating the significance of an optimum temperature in tuber initiation irrespective of high eCO_2 concentrations.

5.2.5 Chemical Analysis

The N, P and K uptake in Chinese potato remained comparable during both the years reflecting the non significant influence of eCO_2 on the plant nutrient contents.

5.2.6 Soil Analysis - Soil Organic Carbon

There was no significant difference in organic carbon content of soil after the experiment during both the years of experimentation. A slight increase was observed with that of initial value in both the years. Kimball *et al*. (2002) opined that the detection of changes in soil organic carbon concentrations is very difficult because the typical net annual additions are very small compared to the size of the pool already present.

FACE experiments for three years in cotton could not recorded statistically significant changes in soil organic carbon in the surface 5cm of soil (Wood *et al.*, 1994). Comparable organic carbon in the soil with elevated CO_2 was also observed by Leavitt *et al.* (1994). Large soil carbon pools and complexities of soil organic carbon turnover make it difficult to detect changes in total soil carbon in short duration experiments even if they extend over several years, such as the Swiss FACE experiment where no significant change on organic carbon content was noticed (Xie *et al*., 2005).

Based on the above findings it could be inferred the management practices evaluated had an pivotal role in determining the crop growth, tuber yield and quality in Chinese potato. The favourable niche created with bed/ ridge method of land preparation, closer spacing, nutrient management including PGPR Mix 1 followed by foliar application of humic acid could effectively modify the source activity and sink strength contributing to the higher yields and economic returns.

Carbon dioxide fertilization study revealed the potential of the substrates, cow dung + coir pith (2:1) + *Pleurotus* + N + P and cow dung + coir pith (2:1) as sources for CO_2 evolution. Increased photosynthesis manifested as the increased canopy growth was evident. However, the study highlighted the negative impact on tuberization contrary to the assumption of increased productivity in tuber crops with CO_2 enrichment. It is deducedthat the soil and air temperature along with the other microclimatic parameters decided the phenological development and assimilate partitioning that influenced tuber development.

The study calls for further investigations on the controls of tuber induction and development under eCO_2 conditions and the physiolocial effects on phloem loading and photosynthate translocation. Manipulation of the modified microclimate to alter the negative effects and formulation of ameliorative measures to beneficially utilize the increased photosynthesis realized with CO_2 enrichment are also crucial.

SUMMARY

6. SUMMARY

The investigation entitled "Resource management for source - sink modulation in Chinese potato [*Plectranthus rotundifolius* (Poir.) Spreng.]" was undertaken at College of Agriculture, Vellayani, Thiruvananthapuram during 2018 - 2021. The experiment aimed to study the influence of planting methods, nutrient management practices and growth promoters on source-sink relationship, tuber yield and quality in Chinese potato, to assess the growth and yield responses of the crop to carbon dioxide fertilization and to work out the economics. The research work was conducted as two separate experiments (i) influence of method of planting, nutrient management and growth promoters on the source-sink relationship, tuber yield and quality in Chinese potato and (ii) influence of carbon dioxide fertilization on the growth, yield and tuber quality in Chinese potato.

The summary of the results of the experiments are given below.

6.1 EXPERIMENT I: INFLUENCE OF METHOD OF PLANTING, NUTRIENT MANAGEMENT AND GROWTH PROMOTERS ON SOURCE - SINK RELATIONSHIP, TUBER YIELD AND QUALITY IN CHINESE POTATO

The experiment I was carried out at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, from October 2019 to February 2020 and the confirmatory experiment during October 2020 to February 2021 with the photo insensitive variety of Chinese potato, Suphala. Field experiment was laid out in split plot design with five methods of planting as main plot and six combinations of nutrient management practices (2) and growth promoters (3) as subplot treatments, in four replications. The main plot treatment, method of planting, included, m_1: bed method (30 cm x 15 cm), m_2: bed method (30 cm x 30 cm), m_3: ridge method (30 cm x 15 cm), m_4: ridge method (30 cm x 30 cm) and m_5: mound method (30 cm x 30 cm). Nutrient management practices, n_1: 60:30:120 kg NPK ha^{-1} + PGPR Mix 1, n_2: 60:30:120 kg NPK ha^{-1} and growth promoters, g_1: humic acid @ 5 g L^{-1}; g_2: benzyl adenine @ 50 mg L^{-1}; g_3: water spray), in combination comprised the subplot treatments. The summary of results of experiment I in the two years is as follows.

Method of planting and nutrient management + growth promoter combination and their interaction significantly influenced the growth attributes in Chinese potato. Plants were taller in the bed planting method with a spacing of 30 cm x 15 cm (m_1) at all stages of observation in both the years of experimentation, except at 90 DAP in the first year. At this stage, the tallest plants were observed in ridge method of planting with 30 cm x 15 cm (m_3) but on par with bed planting at 30 cm x 30 cm (m_2) and 30 cm x 15 cm (m_1). At 120 DAP, bed method of planting with a spacing of 30 cm x 15 cm (m_1) was superior in the first year but comparable with ridge method of planting with 30 cm x 15 cm (m_3) in the second year.

Among the nutrient management + growth promoter combinations, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA (n_1g_2) recorded taller plants at 30 DAP in the first year and was on par with 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) and 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + water spray (n_1g_3). Whereas in the second year, the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) recorded the tallest plants at 30 DAP and was on par with n_1g_2 and n_1g_3. The treatment combination n_1g_1 produced the significantly tallest plants at later stages of observation in both the years.

Interaction effects had a significant influence on plant height only at 60 DAP in the first year, with plants being the tallest in the treatment combination $m_1n_1g_1$. The significantly lowest plant height at 60 DAP was recorded in the treatment combination $m_5n_2g_3$. However, the effects were significant at all the stages of growth in the second year. At 30 DAP, bed method of planting with a spacing of 30 cm x 15 cm along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA ($m_1n_1g_2$) registered higher plant height and on par with $m_1n_1g_1$, $m_1n_1g_3$, $m_3n_1g_1$, $m_3n_1g_2$ and $m_3n_1g_{3.}$ At 60 and 90 DAP, taller plants were produced by the treatment combination $m_1n_1g_1$ and was comparable with $m_1n_1g_2$ and $m_3n_1g_1$. At 120 DAP, plant height was maximum in $m_1n_1g_1$ and did not differ significantly with $m_3n_1g_1$.

Bed and ridge methods of planting at the wider spacing of 30 cm x 30 cm spacing (m_2 and m_4 respectively) recorded higher number of branches per plant and were on par with the mound method at 30 cm x 30 cm spacing at 30 DAP during the first year. At 60 and 90 DAP, m_2 recorded the maximum number of branches per plant and was on par with m_4 during both years. At 120 DAP, higher number of branches per plant was observed in m_2 and comparable with m_4 and m_5 during the first year and m_4 during the second year.

Among sub plots, maximum number of branches per plant at 30 DAP was produced with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) and was comparable with n_1g_2 and n_1g_3 during the first year. At 60 and 90 DAP, n_1g_1 produced the significantly highest number of branches per plant during both the years, whereas, at 120 DAP, the variations were significant in the second year alone and the treatment n_1g_1 produced the maximum number of branches per plant.

In general, $m_2n_1g_1$ proved superior with respect to the number of branches per plant. At 60 DAP, the number of branches per plant was the highest in $m_2n_1g_1$ during both the years and on par with $m_2n_1g_2$ and $m_4n_1g_1$ during first year. Higher number of branches per plant was recorded in $m_2n_1g_1$ at 90 DAP in the first and second year and was statistically similar to $m_4n_1g_1$ in the first year of experimentation. There was a decreasing trend in the number of branches towards harvest. At 120 DAP in the second year, the per plant branch number was the highest in the treatment combination $m_2n_1g_1$.

Plant spread increased gradually as growth advanced upto 90 DAP and thereafter it declined in both the years. The variations were marked at all stages of observation in both the years and the significantly highest plant spread in N-S and E-W direction were observed in the ridge method of planting at 30 cm x 30 cm spacing (m_4). At 30 DAP, all the treatments involving PGPR Mix 1 recorded higher plant spread in both the years and were on par. At 60, 90 and 120 DAP, application of humic acid, n_1g_1, recorded the significantly highest plant spread in both the years. Interaction effects were found to be significant at 30 DAP in the second year alone for plant spread in N-S and E-W direction. The highest spread recorded combination $m_4n_1g_2$ was on par with all combinations containing n_1 with m_2 and m_4.

The number of leaves per plant was maximum at 45 DAP and thereafter declined. The highest number of leaves per plant was recorded in m_2 at all the stages of observation during both the years except in the first year at 135 DAP wherein there was no marked variation. Irrespective of the growth promoter used, n_1 (60:30:120 kg NPK ha^{-1} + PGPR Mix 1) was found to yield a higher number of leaves during both years. At 135 DAP, n_1g_2 and n_2g_2 recorded comparable numbers of leaves per plant in both years of experimentation.

Comparing the interaction effects, bed method of planting at 30 cm x 30 cm spacing along with 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA ($m_2n_1g_2$) recorded a higher number of leaves per plant at 45 DAP during both the years, and was on par with $m_2n_1g_1$ and $m_2n_1g_3$ during the first year and with $m_2n_1g_1$, $m_2n_1g_3$, $m_4n_1g_1$, $m_4n_1g_2$ and $m_4n_1g_3$ during the second year. The treatment combination $m_2n_1g_1$ produced more leaves per plant at 90 DAP during both years, while at 135 DAP, it was comparable.

The highest leaf area was recorded in bed method of planting at 30 cm x 30 cm spacing (m_2) at 45 and 90 DAP during both the years and during the first year, at 45 DAP, m_2 was on par with m_4, ridges at 30 cm x 30 cm spacing. In the second year, m_2 recorded maximum leaf area at 135 DAP which was comparable with the ridge method at 30 cm x 30 cm spacing (m_4). Irrespective of the growth promoter used, inclusion of PGPR Mix 1 resulted in a higher leaf area per plant at 45 DAP compared to sole chemical fertilizer application, the effect being similar in both years. At 90 DAP, the significantly superior leaf area per plant was observed in n_1g_1 in both years. However, at 135 DAP, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA (n_1g_2) recorded higher leaf area during both the years and was on par with n_1g_1 during first year.

With respect to the interaction effects, in the first year, bed method of planting with 30 cm x 30 cm spacing along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + water spray ($m_2n_1g_3$) recorded the maximum leaf area per plant and was on par with $m_2n_1g_1$, $m_2n_1g_2$, $m_4n_1g_1$, $m_4n_1g_2$ and $m_4n_1g_3$ at 45 DAP.

In the second year, at 45 DAP $m_2n_1g_2$ recorded the highest leaf area but was on par with $m_2n_1g_1$ and $m_2n_1g_3$. At 90 DAP, $m_2n_1g_1$ recorded the highest leaf area per plant in the first and second year. It was on par with $m_4n_1g_1$ in the first year.

Bed planting at 30 cm x 15 cm spacing (m_1) recording the significantly highest DMP at 45, 90 and 135 DAP in both the years. Among the subplot treatments, the highest DMP was recorded with application of humic acid along with 60:30:120 kg NPK ha^{-1} and PGPR Mix 1 (n_1g_1) at all stages and was on par with n_1g_2 and n_1g_3 at 45 DAP in both the years. Analyzing the interaction effects, the treatment combination $m_1n_1g_1$ produced the maximum dry matter in both years at 45 DAP on par with $m_1n_1g_2$ in the first year and in the second year on par with $m_1n_1g_2$ and $m_1n_1g_3$. The superiority of $m_1n_1g_1$ was evident in both the years at 90 and 135 DAP, although in the second year it was on par with $m_1n_1g_2$ at 90 DAP.

Significantly the highest CGR computed at 45 days intervals upto 90 DAP was recorded for the bed method of planting at 30 cm x 15 cm spacing (m_1). The lowest CGR values were observed in m_5 (mound method at wider spacing). Between 90-135 DAP, CGR was statistically comparable in ridge and bed methods of planting at the closer spacing in both year experiments. The treatments that included n_1 resulted in comparable CGR during the initial stages up to 45 DAP and later, 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) recorded higher CGR values.

The treatment combination, $m_1n_1g_1$ recorded the maximum CGR during 45-90 DAP and 90-135 DAP in both years. It remained comparable with $m_3n_1g_1$ during 45-90 DAP and 90-135 DAP in the first year whereas in the second year, the highest CGR recorded in $m_1n_1g_1$ was comparable with $m_1n_1g_2$ during 45-90 DAP and with $m_1n_1g_2$, $m_1n_1g_3$ and $m_3n_1g_1$ during 90-135 DAP.

Relative growth rate between 45-90 DAP was higher in ridge method of planting at 30 cm x 30 cm spacing (m_4) and was on par with m_2 and $m_{5,}$ the widely spaced treatments in both the years.

Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) recorded the significantly highest value of RGR during 45-90 DAP in both the years. Between 90-135 DAP, n_1g_1, that showed the significantly highest RGR was on par with n_1g_2 in the first year and with n_1g_2 and n_1g_3 during the second year.

Leaf area index was significantly the highest in m_1 on par with m_3 at all stages of observation during both the years except at 135 DAP in the second year wherein m_3 recorded the highest value and comparable with m_1. Among the combination effects, the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 recorded higher LAI during both the years at 45 DAP. At 90 DAP, the superior LAI was recorded in the application of NPK + PGPR Mix 1 + humic acid (n_1g_1) in both years. At 135 DAP, LAI was maximum in the combination with BA (n_1g_2) in both years and on par with n_1g_1, n_1g_3 and n_2g_2 in the first year and with n_2g_2 in the second year.

Interaction had significant effects on LAI, at 90 DAP alone in the first year. During the second year, the significant influence was visible at 45 and 90 DAP. $m_1n_1g_1$, $m_1n_1g_2$ and, $m_1n_1g_3$ recorded comparable LAI at 45 DAP in the second year. At 90 DAP, $m_3n_1g_1$ recorded the highest LAI but on par with $m_1n_1g_1$ and $m_1n_2g_1$ during the first year, and the treatment combinations, $m_1n_1g_1$, $m_1n_1g_2$ and $m_1n_2g_1$ were on par in the second year.

Net assimilation rate was the highest in bed method of planting at 30 cm x 30 cm spacing (m_2) between 45-90 and 90-135 DAP and on par with that realized in the ridge method planting at 30 cm x 30 cm (m_4) in both the years. The significantly highest NAR was recorded in the combination of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) at 45-90 DAP in both years. During 90-135 DAP, the treatment n_1g_1, n_1g_3 and n_2g_3 were on par in the first year and n_1g_1 and n_1g_3 were on par in the second year. The NAR between 90-135 DAP was significantly the highest in $m_2n_1g_1$ during both the years.

The chlorophyll content estimated at 45 DAP was superior in plants grown on beds at 30 cm x 30 cm spacing (m_2) in the first and second year. At 90 DAP, m_2 recorded higher chlorophyll content in the second year and was comparable with that estimated in the ridge method of planting at 30 cm x 30 cm spacing (m_4).

At 45 DAP, irrespective of the growth promoters, higher chlorophyll was assessed with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1. At 90 DAP, n_1g_1 recorded the highest chlorophyll content during both years.

In the first year, among the combinations, bed method of planting at 30 cm x 30 cm spacing along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + water spray ($m_2n_1g_3$) recorded higher chlorophyll content and was on par with $m_2n_1g_2$ and $m_2n_1g_2$ at 45 DAP. In the second year, higher value of chlorophyll at 45 DAP was produced in the treatment combination $m_2n_1g_2$, but was on par with $m_2n_1g_1$, $m_1n_1g_3$, $m_4n_1g_1$, $m_4n_1g_2$ and $m_4n_1g_3$.

Significant variation in days taken to senescence was observed due to the combination of nutrient management and growth promoter alone. In the first year, the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + BA (n_1g_2) extended the time for senescence significantly, followed by the n_2g_2. In the second year, the effect remained similar, the onset of senescence was the slowest in n_1g_2 which was on par with n_2g_2.

Biomass accumulation (%) in plants varied significantly with the main and subplot treatments during both years. Significantly higher stem biomass was observed in m_3 during both the years and was on par with m_1. Ridge method of planting at a spacing of 30 cm x 30 cm (m_4) produced significantly increased leaf biomass and was on par with m_2 during both the years. Tuber biomass also followed the same trend with m_4 producing significantly higher values (74.61 and 74.96 %) comparable with m_2. Nutrient management and growth promoter combination failed to produce significant variation in stem and leaf biomass. The treatment n_1g_1 recorded significantly higher tuber biomass (68.88 %) during first year alone.

Planting on beds at 30 cm x 30 cm spacing (m_2) registered the maximum per plant number of tubers, tuber yield and marketable tuber yield and average tuber weight during both the years. Comparing the effect on average tuber weight, m_2 was found statistically similar to that in m_4 in the first year and with m_4 and m_5 in the second year. In general, m_3 recorded lower values of for the yield attributes during both the years. Average tuber weight was the lowest in m_3 in the first year and in m_1 in the second year which was on par with m_3.

Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) resulted in significantly highest tuber number, average tuber weight, per plant tuber yield and per plant marketable tuber yield in both the years.

Assessing the interaction effects, the treatment combination involving ridge method of planting at 30 cm x 30 cm along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid ($m_4n_1g_1$) produced the maximum number of tubers per plant in the first year and was on par with $m_2n_1g_1$. During second year, it was the highest in the combination $m_2n_1g_1$. Per plant tuber yield and marketable tuber yield were the highest in $m_2n_1g_1$ during both the years of experimentation. Per plant tuber yield in $m_2n_1g_1$ was comparable with $m_4n_1g_1$ in the first year. The significantly lowest number of tubers was produced in $m_4n_2g_3$ during first year and in $m_3n_2g_3$ during second year. The significantly lowest per plant tuber yield and marketable tuber yield were produced in $m_3n_2g_3$ during both the years.

There was significant variation in percentage of marketable tuber per plant realized due to treatments in both the years. In the first year, ridge method of planting with 30 cm x 30 cm (m_4) recorder higher percentage of marketable tubers per plant and was on par with m_2. In the second year, mound method with 30 cm x 30 cm spacing recorded the significantly highest percentage of marketable tuber per plant. Significantly higher tuber yield and marketable tuber yield per hectare were recorded in bed method of planting with 30 cm x 15 cm spacing (m_1) during both the years. Whereas bed method of planting at 30 cm x 30 cm spacing (m_2) led to the significantly highest value of percentage marketable tuber yield in both the years and was comparable with m_4 in the second year.

Among the subplot treatments, application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) recorded a higher percentage of marketable tubers, per hectare tuber yield, per hectare marketable tuber yield and percentage marketable tuber yield in both the years and harvest index in the first year. Percentage marketable tubers computed in n_1g_1 was on par with n_1g_2 in the first year. Higher percentage marketable tuber yield noted in n_1g_1 was on par with n_1g_2 in the second year.

Significantly maximum percentage of marketable tubers per plant was noted in $m_2n_1g_1$ in the second year and the lowest in $m_1n_2g_{3.}$ The treatment combination $m_1n_1g_1$ recorded superior per hectare tuber and marketable tuber yield in both the years. The lowest was in $m_5n_2g_3$. Pooled analysis of per hectare tuber yield (23.38 t ha^{-1}) and marketable tuber yield (20.67 t ha^{-1}) also revealed the same trend. Significantly highest percentage marketable tuber yield was observed in $m_2n_1g_1$ during first year.

Main plot as well as interaction effect did not cause significant variations in the starch and protein content in both the years. But amongst the subplot treatments, the combination of application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid produced the significantly higher protein content in both the years (7.71 and 7.94 % respectively). There was no variation observed in sucrose content due to main plot, sub plot and interaction effect in both the years under study.

Bed method of planting with 30 cm x 15 cm spacing recorded significantly the highest N, P and K uptake during both years. The significantly highest P uptake computed in $m_{1,}$ during the second year was on par with m_3. With respect to the subplot effects, the significantly highest N, P and K uptake were observed in the combination, 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid during both the years. In the case of interaction effects, the K uptake was the highest in $m_1n_1g_1$ in both years but in the second year it remained on par with $m_1n_1g_2$.

The soil pH and soil organic carbon did not vary significantly with methods of planting and combination of nutrient management and growth promoter in both the years whereas significant variations were recorded in available NPK due to treatments. During both years, available N, P and K status were the highest in mound method of planting at 30 cm x 30 cm (m_5) spacing and comparable with m_4 and m_2. Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid recorded higher available N and was on par with n_1g_2 and n_1g_3.

Application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1+ water spray recorded the highest P and K status, on par with n_1g_1 and n_1g_2 in both of the years.

Exploring the interaction effects, the significantly highest P status was observed in the treatment combination $m_5n_1g_1$ in both the years and in the second year it was on par with $m_5n_1g_3$. Higher available K recorded in the treatment combination $m_4n_1g_3$ was on par with $m_4n_1g_1$, $m_4n_1g_2$, $m_4n_2g_3$, $m_2n_2g_2$, $m_5n_1g_1$, $m_5n_1g_2$ and $m_5n_1g_3$ in the first year. In the second year, $m_5n_1g_3$ recorded the highest K status and was on par with $m_5n_1g_2$, $m_5n_1g_1$, $m_4n_2g_3$, $m_4n_1g_1$, $m_4n_1g_2$, $m_4n_1g_3$ and $m_2n_2g_2$.

Bacterial, fungal and actinomycete population enumerated in soil were higher in the bed method of planting at 30 cm x 15 cm spacing (m_1). Higher bacterial population in m_1 was found on par with m_3 in both the years. The lowest count was in the mound method of planting at 30 cm x 30 cm spacing (m_5) during both years. Comparable microbial populations were enumerated with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 irrespective of the growth promoters included in the treatments.

Among the interaction effects, bacterial population was significantly higher in the treatment combination $m_1n_1g_3$ and on par with $m_1n_1g_2$, $m_1n_1g_1$, $m_3n_1g_1$ and $m_3n_1g_3$ in the first year. In the second year, $m_1n_1g_2$ recorded higher bacterial population on par with $m_1n_1g_1$, $m_1n_1g_3$ and $m_3n_1g_2$. The treatment combination $m_1n_1g_3$ recorded higher fungal population and was on par with $m_1n_1g_2$ and $m_1n_1g_1$ in both years. Actinomycete counts were higher in $m_1n_2g_3$ in the first year and were comparable with $m_1n_1g_1$, $m_1n_1g_2$, $m_1n_1g_3$, $m_2n_1g_1$, $m_1n_2g_2$ and $m_5n_1g_2$. In the second year, $m_1n_2g_1$ recorded maximum population but on par with $m_1n_1g_1$, $m_1n_1g_2$, $m_1n_1g_3$, $m_1n_2g_2$, $m_1n_2g_3$, $m_3n_1g_1$, $m_3n_1g_2$ and $m_3n_1g_3$.

Markedly higher de-hydrogenase activity was recorded in m_1 in both the years and was on par with m_3 in the second year. The combination of NPK with growth promoter also significantly influenced the de-hydrogenase activity in both the years of experimentation. The treatment n_1g_1 recorded superior values of dehydrogenase activity in both the years and were on par with n_1g_3 in the first year and with n_1g_2 and n_1g_3 in the second year. Among the treatment combinations, bed planting at 30 cm x 15 cm spacing (m_3) with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1, irrespective of growth promoters applied recorded comparable value of dehydrogenase activity wherein $m_1n_1g_2$ recorded the highest value in the first year and $m_1n_1g_2$ and $m_1n_1g_3$ in the second year.

Economic analysis revealed that bed method of planting at 30 cm x 15 cm spacing along with the application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid was most profitable, net returns and BCR being ₹ 625639 ha^{-1} and 3.72 respectively in the first year and ₹ 676953 ha^{-1} and 3.95 in the second year respectively. The pooled mean of treatment combinations also revealed the same trend.

6.2 EXPERIMENT II : INFLUENCE OF CARBON DIOXIDE FERTILIZATION ON GROWTH, YIELD AND TUBER QUALITY IN CHINESE POTATO

Carbon dioxide fertilization conducted in the trench method with different substrates as sources for CO_2 evolution revealed enhanced vegetative growth at the expense of tuber production in Chinese potato.

The different substrates used in the trenches varied in the quantum of CO_2 evolved with the maximum evolution in cow dung + coir pith (2:1) *Pleurotus* + N + P (s_5) and cow dung + coir pith (2:1) (s_3). The peak evolution was seen in the first two weeks after substrate application and thereafter declined. Air and soil temperatures monitored revealed higher values in the trenches compared to the ambient conditions.

Carbon dioxide fertilization had a significant influence on growth attributes in Chinese potato. Significant variations in plant height were recorded in all the growth stages except at 120 DAP during both the years of study.

Plants were significantly taller in the treatment in which cow dung + coir pith (2:1) was used as substrate (s_3) at 30 DAP, but on par with coir pith + *Pleurotus* + N + P ((s_4) and s_3 + *Pleurotus* + N + P (s_5) during the first year and it was also comparable with plants grown in the trench with cow dung alone as substrate (s_1). At 60 and 90 DAP, the highest plant height was observed in treatment s_5 and on par with s_4 during the first year and s_3 and s_4 during the second year at 60 DAP. The shortest plants were observed in trenches with no substrate application (s_0). Plant height did not differ significantly at 120 DAP during both years.

The significantly highest number of branches, leaves per plant and leaf area at 30 DAP were recorded in the plants grown in s_3 during both the years of experimentation and on par with $s_{5.}$ At 60, 90 and 120 DAP, the attributes were the highest in s_5 during both years.

At 45 DAP, maximum chlorophyll content was recorded in the plants grown in the trench with cow dung + coir pith (2:1) substrate during both the years followed by the treatment s_5 (s_3 + *Pleurotus* + N + P), whereas at 90 DAP, s_5 was superior to all other treatments. Significant differences were not observed concerning chlorophyll content at 135 DAP during both years.

Senescence was earlier in CO_2 fertilized plants compared to those in the treatment with no substrate application.

The highest stem, leaf, root, and total biomass per plant were recorded in s_5 during both the years of experimentation and it remained the lowest when grown without substrate application.

Tuberisation was not observed in the plants in any of the treatments during both years.

The plant N, P and K uptake did not vary in the treatments in both years.

Among the substrates used, the initial C: N ratio was the highest in coir pith (s_2) and was narrowed down with the decomposition and CO_2 release.

There was no significant difference in the organic carbon content of the soil after the experiment during both the years of experimentation.

The results of the research work revealed the most suitable combination in Chinese potato for increased marketable tuber yield, net returns and B: C ratio to include planting of the cuttings on beds at 30 cm x 15 cm spacing along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 @ 2 per cent, 5 g per plant thrice, at basal, 30 and 60 DAP + and spraying humic acid @ 5 g L^{-1} twice, at 45 and 75 DAP ($m_1n_1g_1$). Application of PGPR Mix 1 + humic acid proved to be superior in terms of the tuber quality attributes, starch and protein content. Soil chemical and biological properties were favourably influenced by the application of PGPR Mix 1 irrespective of the growth promoter spray. Carbon dioxide fertilization significantly enhanced the vegetative growth in Chinese potato at the expense of tuber development

Future line of work

- Inclusion of liquid biofertilizer in combination with other organic nutrient sources
- Phenological studies, especially the tuberisation pattern in relation to environmental effects
- Nutrient mineralization and absorption pattern under eCO_2 conditions
- Rhizospheric effects in response to land configuration and biofertilizers
- Residual effect of biofertilizers applied and allelopathic effect may be explored in cropping systems
- Molecular responses of the Chinese potato towards CO_2 fertilization
- Influence of day/night temperature on Chinese potato with and without CO_2 enrichment

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APPENDICES

APPENDIX I

Weather parameters during experiment I (October 2019 to February 2020)

Standard week	Temperature (°C)		Mean relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
40	31.5	24.7	81.80	0
41	31.1	24.4	84.36	133.1
42	30.9	24.2	87.57	125.7
43	30.9	23.6	84.50	42.8
44	30.9	24.0	86.86	105.6
45	30.3	24.8	78.71	0
46	28.8	24.6	79.07	9.0
47	32.1	24.3	83.43	49.9
48	32.6	24.5	81.57	31.0
49	32.0	24.1	80.43	38.1
50	32.2	23.6	80.93	53.0
51	31.4	23.9	82.64	41.4
52	31.9	23.8	80.88	60.5
1	32.2	24.1	79.86	0
2	32.0	22.7	79.85	45.0
3	32.2	22.5	78.00	10.0
4	32.7	23.0	77.75	0
5	32.7	22.3	75.30	0
6	32.7	23.2	77.35	0
7	33.2	23.7	74.50	0
8	33.0	22.8	73.50	0

APPENDIX II

Weather parameters during experiment I (October 2020 to February 2021)

Standard week	Temperature (°C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
40	31.9	25.3	85.0	0
41	30.7	24.0	90.8	118.2
42	30.7	24.8	87.3	26.7
43	31.9	25.3	86.5	0.8
44	32.4	25.2	81.6	0
45	33.2	25.8	84.2	2.4
46	30.6	24.5	90.4	71.0
47	32.6	24.9	83.5	0
48	33.0	25.1	83.4	11.7
49	31.3	24.3	87.5	60.9
50	32.8	24.4	84.1	4.0
51	32.2	23.9	88.9	9.5
52	33.2	23.6	82.1	0
1	32.0	23.6	89.4	32.2
2	30.4	24.0	91.1	45.0
3	32.0	24.2	85.0	1.4
4	32.6	22.2	81.9	0
5	33.0	23.7	80.3	0
6	33.0	21.4	82.0	0
7	33.0	20.4	79.9	0
8	33.2	23.5	80.5	0

APPENDIX III

Weather parameters during experiment II (November 2019 to July 2020)

Standard week	Temperature (°C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
45	32.5	25.0	78.60	0
46	28.8	24.6	79.07	9.0
47	32.1	24.3	83.43	49.9
48	32.6	24.5	81.57	310
49	32.0	24.1	80.43	38.1
50	32.2	23.6	80.93	53.0
51	31.4	23.9	82.64	41.4
52	31.9	23.8	80.88	60.5
1	32.2	24.1	79.86	0
2	32.0	22.7	79.85	45.0
3	32.2	22.5	78.00	10.0
4	32.7	23.0	77.75	0
5	32.7	22.3	75.30	0
6	32.7	23.2	77.35	0
7	33.2	23.7	74.50	0
8	33.1	23.2	74.64	0
9	33.2	23.4	75.25	37.6
10	33.2	24.3	76.71	3.0
11	33.4	24.6	73.29	0
12	33.7	25.0	74.21	11.7
13	34.1	25.1	72.21	0
14	34.1	25.0	72.29	19.6
15	33.9	25.6	73.86	2.9
16	34.6	25.9	72.83	4.8
17	34.4	25.9	75.43	60.3
18	34.2	26.2	73.57	43.0
19	32.6	25.7	84.79	105.7
20	31.5	24.9	85.86	125.7
21	32.1	25.7	85.71	123.4
22	31.4	24.6	87.86	177.7
23	30.6	24.5	86.57	145.8
24	32.6	25.7	82.29	15.0
25	32.3	24.4	81.21	12.8
26	31.3	24.7	83.29	48.4
27	32.2	25.0	76.50	0

APPENDIX IV

Weather parameters during experiment II (October 2020 to March 2021)

Standard week	Temperature (°C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
40	31.9	25.3	85	0
41	30.7	24.0	90.8	118.2
42	30.7	24.8	87.3	26.7
43	31.9	25.3	86.5	0.8
44	32.4	25.2	81.6	0
45	33.2	25.8	84.2	2.4
46	30.6	24.5	90.4	71.0
47	32.6	24.9	83.5	0
48	33.0	25.1	83.4	11.7
49	31.3	24.3	87.5	60.9
50	32.8	24.4	84.1	4.0
51	32.2	23.9	88.9	9.5
52	33.2	23.6	82.1	0
1	32.0	23.6	89.4	32.2
2	30.4	24.0	91.1	45.0
3	32.0	24.2	85.0	1.4
4	32.6	22.2	81.9	0
5	33.0	23.7	80.3	0
6	33.0	21.4	82.0	0
7	33.0	20.4	79.9	0
8	33.4	23.4	81.3	0
9	33.4	22.5	78.0	0

APPENDIX V

Average cost of inputs and market price of the produce

Items	Costs (₹)
Inputs	
Planting material (seed tuber)	40 kg^{-1}
Lime	15 kg^{-1}
FYM	5 kg^{-1}
Urea	10 kg^{-1}
Rajphos	15 kg^{-1}
Muriate of potash	17 kg^{-1}
Insecticide (CORAGEN®)	21 mL^{-1}
PGPR Mix 1	80 kg^{-1}
Humic acid	622 kg^{-1}
Benzyl adenine	1710 g^{-1}
Labour wages	
Men	750 per day
Women	650 per day
Produce	
Marketable tubers	40 kg^{-1}
Less marketable tubers	20 kg^{-1}

RESOURCE MANAGEMENT FOR SOURCE – SINK MODULATION IN CHINESE POTATO [*Plectranthus rotundifolius* (Poir.) Spreng.]

by

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ABSTRACT
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ABSTRACT

The research work entitled ‘Resource management for source-sink modulation in Chinese potato [*Plectranthus rotundifolius* (Poir.) Spreng.]’ was undertaken at College of Agriculture, Vellayani during 2018 – 2021. The main objectives were to study the influence of planting methods, nutrient management practices and growth promoters on source-sink relationship, tuber yield and quality in Chinese potato, to assess the growth and yield responses of the crop to carbon dioxide (CO_2) fertilization and to work out the economics.

The investigation was carried out as two experiments: i) influence of planting methods, nutrient management practices and growth promoters on source - sink relationship, tuber yield and quality and ii) influence of CO_2 fertilization on growth and yield responses in Chinese potato. The photo insensitive variety Suphala, released by Kerala Agricultural University (KAU), was used for the study. Experiment I was conducted during October 2019- February 2020 and repeated during 2020-2021 for confirmation. It was laid out in split plot design with five methods of planting as main plots and six combinations of two nutrient management practices and three growth promoters as sub plot treatments, in four replications. The methods of planting included were m_1: bed method (30 cm x 15 cm), m_2: bed method (30 cm x 30 cm), m_3: ridge method (30 cm x 15 cm), m_4: ridge method (30 cm x 30 cm) and m_5: mound method (30 cm x 30 cm). The combinations comprised nutrient management practices (n_1: 60:30:120 kg NPK ha^{-1} + PGPR Mix 1, n_2: 60:30:120 kg NPK ha^{-1}) and growth promoters (g_1: humic acid @ 5 g L^{-1}, g_2: benzyl adenine @ 50 mg L^{-1} and g_3: water spray). PGPR Mix 1 (2 %) was applied @ 5 g per plant, thrice, at the time of planting, 30 DAP and 60 DAP in n_1 and growth promoters were sprayed 45 and 75 DAP. Other cultural operations were done as per package of practices of KAU.

Bed method of planting at 30 cm x 15 cm (m_1) produced significantly taller plants with higher leaf area index (LAI), dry matter production (DMP) and crop growth rate (CGR) in both the years. Planting at the wider spacing (30 cm x 30 cm) on beds (m_2) or ridges (m_4) resulted in higher and comparable values for

number of branches and plant spread (N-S and E-W), while m_2 showed superiority in the number of leaves and leaf area per plant at 45 and 90 DAP. The wider spacing, irrespective of the method of planting, revealed markedly higher relative growth rate (RGR) during 45-90 DAP and the trend remained similar in both years. Significantly higher net assimilation rate (NAR) between 45-90 and 90-135 DAP, and chlorophyll content were noted in m_2. Higher chlorophyll content in m_2 was on par with m_4 during second year.

Per plant tuber attributes (number of tubers, tuber yield, marketable tuber yield and average tuber weight) were found superior in bed planting at 30 cm x 30 cm. But, average tuber weight was comparable with m_4 in the first year and with m_4 and m_5 in the second year. Per hectare tuber yields were significantly the highest in the bed method of planting at 30 cm x 15 cm spacing, during both the years with a pooled mean of 20.93 t ha^{-1}. The treatment also showed the maximum uptake of N, P and K. Soil available N, P and K status were the highest in mound method at 30 cm x 30 cm (m_5) and on par with m_4 and m_2. Bacterial, fungal and actinomycete population and dehydrogenase activity were higher in the bed/ridge method of planting at 30 cm x 15 cm spacing (m_1 and m_3).

The combination of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid (n_1g_1) resulted in significantly higher growth attributes (plant height, number of branches and plant spread) while at 135 DAP, n_1g_2 recorded the maximum number of leaves, leaf area per plant, LAI and delayed senescence in both the years. Physiological parameters (DMP, CGR, RGR, NAR) yield attributes, per hectare tuber yield, marketable tuber yield, percentage marketable tuber yield, N, P, K uptake, starch and protein content were superior in n_1g_1. The tuber yield and marketable tuber yield (pooled) were 21.10 and 18.34 t ha^{-1} respectively. Soil available N, P, K status, microbial count and dehydrogenase activity were markedly higher in treatments involving PGPR Mix 1 (n_1) compared to that without PGPR Mix 1, nevertheless, remained comparable among n_1g_1, n_1g_2 and n_1g_3.

Land configuration (bed/ridge) with planting at wider spacing and inclusion of PGPR and humic acid proved superior with respect to the number of branches, leaves per plant and leaf area. Leaf area index was significantly the highest in $m_3n_1g_1$ in the first year and $m_1n_1g_1$ in the second year at 90 DAP. The combination $m_4n_1g_1$, produced the maximum number of tubers per plant (23.8) in the first year on par with $m_2n_1g_1$ (23.6), whereas during the second year it was the highest (25.0) in $m_2n_1g_1$. Maximum per plant tuber yield (189.48 and 198.95 g), marketable tuber yield (170.37 and 179.45 g) and percentage of marketable tubers (73.06 and 70.67) were noted in $m_2n_1g_1$ during both years.

The treatment combination $m_1n_1g_1$ recorded the highest DMP and per hectare tuber yield with a pooled mean of 23.38 t ha^{-1}. The percentage of marketable tuber yields increased by nearly 10 per cent over $m_1n_2g_3$ in the two years. Potassium uptake was the highest in $m_1n_1g_1$ and remained comparable with $m_1n_1g_2$ in the second year. Irrespective of growth promoters applied, inclusion of PGPR Mix 1 (n_1) resulted in higher soil available P and K status in the widely spaced planting and the maximum dehydrogenase activity and microbial counts were enumerated in the closely spaced planting on beds (m_1). Bed method of planting at 30 cm x 15 cm spacing along with application of 60:30:120 kg NPK ha^{-1} + PGPR Mix 1 + humic acid ($m_1n_1g_1$) was the most profitable resource management practice, pooled mean of economics of cultivation revealed maximum net returns and BCR of ₹ 651296 ha^{-1} and 3.83 respectively.

The CO_2 fertilization study was conducted in trenches (2 m x 1 m x 1 m) in completely randomized design with six treatments (substrates for CO_2 evolution) replicated thrice, during November 2019- July 2020 and October 2020-March 2021. The treatments included, s_0: no substrate, s_1: cow dung, s_2: coir pith, s_3: cow dung + coir pith (2:1), s_4: s_2 + *Pleurotus* 1g kg^{-1} + N + P (2% w/w) and s_5: s_3 + *Pleurotus* 1g kg^{-1} + N + P (2% w/w). Cuttings of Chinese potato were planted directly in soil in the first year and in grow bags during the second year. Organic substrates (as per treatment) were spread at the trench base to a thickness of 5 cm, taking precautions to avoid direct contact of the substrates with the cuttings planted directly in soil. The trenches were kept covered with a dome prepared of 200 µ uv stabilised polythene sheet fixed on a metal frame, daily from 4.00 pm to 10.30 am.

In all the substrate applied treatments, maximum release of CO_2 (501 to 858 ppm) occurred during the first two weeks of application and thereafter it declined. The highest peak of CO_2 concentration (858 ppm) at two weeks of application was observed in s_5 followed by s_3, (752 ppm). Relatively higher air and soil temperatures were observed in trenches during both the years of study.

Significantly higher growth attributes at 30 DAP were observed in plants grown in the trench filled with cow dung and coir pith in 2:1 ratio (s_3) comparable with treatments containing cow dung and additives (s_5). The superiority of s_5 on growth attributes were evident at the later stages of growth. Chlorophyll contents (1.147 and 1.193 mg g^{-1}) were maximum in s_3 applied trenches at 45 DAP, whereas s_5 recorded superior values at 90 DAP (1.153 and 1.193 mg g^{-1}). Initiation of senescence was significantly earlier in CO_2 fertilized plants and the highest biomass per plant was recorded in s_5. Nevertheless, despite an increased above ground biomass with elevated CO_2, tuber development was not observed in any of the treatments.

Based on the results of the experiments, it could be concluded that bed/ ridge method of land preparation with planting at 30 cm x 30 cm spacing in combination with an NPK dose of 60:30:120 kg ha^{-1} + PGPR Mix 1 + humic acid significantly improved the growth parameters (source) and yield attributes (sink) in Chinese potato. A closer planting (30 cm x 15 cm) on beds and application of 60:30:120 kg NPK ha^{-1} through chemical fertilizers, PGPR Mix 1 (2 %) @ 5 g per plant thrice, as basal, 30 and 60 DAP along with foliar sprays of humic acid @ 5 g L^{-1} (45 and 75 DAP) can be recommended for superior marketable tuber yields, higher net returns and B: C ratio. The results of the CO_2 fertilization study indicated that elevated CO_2 enhanced the vegetative growth in Chinese potato at the expense of tuber development.

സംഗ്രഹം

കൂർക്കയിലെ സ്രോതസ്സ്–നിർഗമക്രമീകരണത്തിനായുള്ള വിഭവ പരിപാലനം എന്ന വിഷയത്തെ ആസ്പദമാക്കി വെള്ളായണി കാർഷിക കോളേജിൽ 2018–21 കാലയളവിൽ ഒരു ഗവേഷണ പഠനം നടത്തുകയുണ്ടായി. നടീൽ രീതി, പോഷക പരിപാലനം, വളർച്ചാ ത്വരിതങ്ങൾ എന്നിവയ്ക്കു കൂർക്കയിൽ സ്രോതസ്സ്–നിർഗമവുമായുള്ള ബന്ധം, വിളവ്, ഗുണ നിലവാരം എന്നിവയിലുള്ള പ്രഭാവം പഠിക്കുക, വരവ് ചെലവ് തിട്ടപ്പെടുത്തുക, കാർബൺ ഡൈഓക്സൈഡ് (CO_2) സമൃദ്ധീകരണം മൂലം വളർച്ചയിലും വിളവിലും ഉള്ള പ്രതികരണം കണക്കാക്കുക, എന്നിവയായിരുന്നു പ്രധാന ലക്ഷ്യങ്ങൾ. രണ്ടു വ്യത്യസ്ത പരീക്ഷണങ്ങളായിട്ടാണ് ഗവേഷണം നടത്തിയത്. ഋതു ഗുണസ്വഭാവം ഇല്ലാത്ത സുഫല എന്ന കൂർക്കയിനം ആണ് പരീക്ഷണത്തിനായി ഉപയോഗിച്ചത്.

കാർഷിക പരിപാലന മുറകളായ നടീൽ രീതി, പോഷക പരിപാലനം, വളർച്ചാ ത്വരിതങ്ങളുടെ ഉപയോഗം കൂർക്കച്ചെടികളുടെ വളർച്ചയിലും വിളവിലുമുള്ള സ്വാധീനം ഉൾപ്പെടുത്തിയ ഒന്നാമത്തെ പരീക്ഷണം ഒക്ടോബർ മുതൽ ഫെബ്രുവരി വരെ ഉള്ള കാലയളവിൽ 2019–20 ലും 2020–21 ലും ചെയ്യുകയുണ്ടായി. സ്പ്ലിറ്റ് പ്ലോട്ട് ഡിസൈൻ ആണ് പരീക്ഷണത്തിനായി തിരഞ്ഞെടുത്തത്. അഞ്ച് രീതിയിലുള്ള നടീൽ മാർഗ്ഗങ്ങൾ മെയിൻ പ്ലോട്ട് ട്രീറ്റ്മെന്റുകൾ ആയും രണ്ടു പോഷക പരിപാലന രീതികൾ, മൂന്ന് വളർച്ചാ ത്വരിതങ്ങൾ എന്നിവയുടെ സമ്മിശ്രണം ആയി ആറു സബ് പ്ലോട്ട് ട്രീറ്റ്മെന്റുകളും ഉണ്ടായിരുന്നു. നാലു റെപ്ലിക്കേഷനും നിലനിർത്തി. തലപ്പുകൾ തടങ്ങളിൽ 30 സെന്റീമീറ്റർ x 15 സെന്റീമീറ്റർ അകലം, തടങ്ങളിൽ 30 സെന്റീമീറ്റർ x 30 സെന്റീമീറ്റർ അകലം, വാരങ്ങളിൽ 30 സെന്റീമീറ്റർ x 15 സെന്റീമീറ്റർ അകലം, വാരങ്ങളിൽ 30 സെന്റീമീറ്റർ x 30 സെന്റീമീറ്റർ അകലം, കൂനകളിൽ 30 സെന്റീമീറ്റർ അകലം എന്നിവ ആയിരുന്നു നടീൽ രീതികൾ. പോഷക പരിപാലനത്തിനായി പാക്യജനകം, ഭാവഹം, ക്ഷാരം എന്നിവ ഹെക്ടർ ഒന്നിന് 60:30:120 കിലോഗ്രാം നിരക്കാക്കി, ജീവാണു വളക്കൂട്ട് പി ജി പി ആർ മിക്സ് 1, ചേർത്തും ചേർക്കാതെയും പരീക്ഷിച്ചു. ഹ്യൂമിക് ആസിഡ് ഒരു ലിറ്ററിനു അഞ്ച് ഗ്രാം, ബെൻസെയിൽ അഡിനൈൻ 50 പി പി എം, വെള്ളം തളിക്കൽ എന്നീ വളർച്ചാ ത്വരിതങ്ങൾ പത്രപോഷണ രീതികളായും അനുവർത്തിച്ചു. പി ജി പി ആർ

ഉൾപ്പെടുത്തിയ ട്രീറ്റ്മെന്റുകളിൽ ഇത് രണ്ടു ശതമാനം വീര്യത്തിൽ 5 ഗ്രാം വീതം ഒരു ചെടിക്ക് എന്ന തോതിൽ നടുമ്പോഴും നട്ട് 30, 60 ദിവസങ്ങൾക്കു ശേഷവും നൽകി. വളർച്ചാ ത്വരിതങ്ങൾ പത്രപോഷണത്തിലൂടെ നട്ട് 45, 75 ദിവസങ്ങൾ കഴിഞ്ഞും ആണ് നൽകിയത്. മറ്റു പരിപാലനമുറകൾ നിർദിഷ്ട രീതികളിൽ അനുവർത്തിക്കുകയും ചെയ്തു.

തടങ്ങളിൽ 30 സെന്റീമീറ്റർ x 30 സെന്റീമീറ്റർ അകലത്തിൽ നടുന്നത് വളർച്ചയും ഒരു ചെടിയിൽ നിന്ന് ലഭിക്കുന്ന കിഴങ്ങുകളുടെ എണ്ണവും തൂക്കവും കൂട്ടുന്നതായി കണ്ടു. സബ് പ്ലോട്ട് ട്രീട്മെന്റുകളിൽ പാക്യജനകം, ഭാവഹം, ക്ഷാരം എന്നിവ ഹെക്ടർ ഒന്നിന് 60:30:120 കിലോഗ്രാം എന്നതിനോടൊപ്പം ജീവാണു വളക്കൂട്ട് പി ജി പി ആർ മിക്സ് 1 + ഹ്യൂമിക് ആസിഡ് പത്രപോഷണം നടത്തുന്നതുമാണ് മികച്ചതായി തെളിഞ്ഞത്. എന്നാലിത് ഒരു ഹെക്ടർ സ്ഥലത്തെ വിളവ് തിട്ടപ്പെടുത്തിയപ്പോൾ 30 സെന്റീമീറ്റർ x 15 സെന്റീമീറ്റർ അകലത്തിൽ നടുന്നതാണ് മികവുറ്റതായി കണ്ടത്. രണ്ടു വർഷത്തെ പരീക്ഷണങ്ങളിൽ നിന്ന് 20.93 ടൺ വിളവ് കണക്കാക്കി. ഇതിൽ 83.42 ശതമാനം കിഴങ്ങുകളും തൂക്കം അഞ്ച് ഗ്രാമിൽ കൂടിയവയായിരുന്നു. മേൽപ്പറഞ്ഞ പരിപാലന മുറകൾ ചെടികളുടെ കായിക വളർച്ചയും പ്രകാശ സംശ്ലേഷണവും വർധിപ്പിക്കുകയും കൂടുതൽ ഫോട്ടോസിന്തേറ്റ്സ് കിഴങ്ങുകളിലേക്ക് നീങ്ങുന്നതിനു ഉതകുകയും അതു മൂലം അധികം വിളവും വരുമാനവും ലഭിക്കുന്നതായി കണ്ടെത്തി. ഇതിൽ നിന്ന് കൂർക്കകൃഷിയിൽ തടങ്ങളിൽ 30 സെന്റീമീറ്റർ x 15 സെന്റീമീറ്റർ അകലത്തിൽ തലകൾ നട്ട് പാക്യജനകം, ഭാവഹം, ക്ഷാരം എന്നിവ ഹെക്ടർ ഒന്നിന് 60:30:120 കിലോഗ്രാം, ജീവാണു വളക്കൂട്ട് പി ജി പി ആർ മിക്സ് 1 (2 %) നടുമ്പോഴും, നട്ട് 30, 60 ദിവസങ്ങൾക്കു ശേഷവും നൽകുന്നതോടൊപ്പം ഹ്യൂമിക് ആസിഡ് അഞ്ച് ഗ്രാം ഒരു ലിറ്റർ വെള്ളത്തിൽ കലക്കി നട്ട് 45, 75 ദിവസങ്ങൾ കഴിഞ്ഞും പത്രപോഷണം വഴി നൽകുന്നത് അത്യുത്തമവും ലാഭകരവുമായി കണ്ടെത്തി.

കാർബൺ ഡൈഓക്സൈഡ് സമ്പുഷ്ടീകരണത്തിനു കൂർക്കയിലെ സ്രോതസ്സ്-നിർഗമം, വിളവ്, എന്നിവയിലുള്ള സ്വാധീനം പഠിക്കുക എന്നതായിരുന്നു രണ്ടാമത്തെ പരീക്ഷണം. കമ്പ്ലീറ്റലി റാൻഡമൈസെഡ് ബ്ലോക്ക് ഡിസൈനിൽ ആറു ട്രീറ്റ്മെന്റ്കളും മൂന്ന് റെപ്ലിക്കേഷനും നിലനിർത്തിക്കൊണ്ടായിരുന്നു പഠനം.

നവംബർ 2019 മുതൽ ജൂലൈ 2020 വരെ ആദ്യ വർഷവും രണ്ടാം വർഷം ഒക്ടോബർ 2020 മുതൽ മാർച്ച് 2021 വരെയും പരീക്ഷണം നടത്തി. CO_2 ബഹിർഗമനത്തിനായി വിവിധ ജൈവ വസ്തുക്കൾ ആണ് ഉപയോഗിച്ചത്. ചാണകം, ചകിരിച്ചോർ, ചാണകവും ചകിരിച്ചോറും 2: 1 എന്ന അനുപാതത്തിൽ ഉള്ള മിശ്രിതം, പ്ലൂറോട്ടസ് കൂൺ വിത്ത് (1 %), പാക്യജനകം, ഭാവഹം, (2 % വീതം) എന്നിവ ചേർത്ത ചകിരിച്ചോർ, പ്ലൂറോട്ടസ് കൂൺ വിത്ത് (1 %), പാക്യജനകം, ഭാവഹം, (2 % വീതം) എന്നിവ ചേർത്ത ചാണകവും ചകിരിച്ചോറും 2:1 എന്ന അനുപാതത്തിൽ ഉള്ള മിശ്രിതം, സാധാരണ രീതിയിൽ മിശ്രിതം ഒന്നുമില്ലാതെ, മുതലായവ ആയിരുന്നു ട്രീറ്റ്മെന്റുകൾ. രണ്ട് മീറ്റർ നീളവും ഒരു മീറ്റർ വീതിയും ഒരു മീറ്റർ താഴ്ചയുമുള്ള കുഴികളിലാണ് പരീക്ഷണം നടത്തിയത്. ജൈവ മിശ്രിത വസ്തുക്കൾ ട്രീറ്റ്മെന്റ് അനുസരിച്ച് അഞ്ച് സെന്റീമീറ്റർ കനത്തിൽ കുഴികളുടെ തറയിൽ നിരത്തി. ഒന്നാം വർഷം കൂർക്കത്തലപ്പുകൾ മണ്ണിൽ നേരിട്ടും രണ്ടാം വർഷം ഗ്രോ ബാഗിലുമായിട്ടാണ് നട്ടത്. ചെടികൾ നേരിട്ട് ജൈവ മിശ്രിത വസ്തുക്കളുമായി സമ്പർക്കത്തിൽ വരുന്നത് ഒഴിവാക്കിയായിരുന്നു ഇത് ചെയ്തത്. 200 മൈക്രോൺ യു വി സ്റ്റബിലൈസ്ഡ് പോളി എത്തിലീൻ ഷീറ്റുകൾ അർദ്ധവൃത്താകാരത്തിലുള്ള ഇരുമ്പു കൊണ്ട് നിർമ്മിച്ച ആകൃതിയിലുള്ള ചട്ടക്കൂടിന്മേൽ ഒട്ടിച്ച് മേൽക്കൂരയായി ഉപയോഗിച്ചു. വൈകിട്ട് 4 മണി തൊട്ട് രാവിലെ 10.30 മണി വരെ ഓരോ കുഴിയും ചട്ടക്കൂട് കൊണ്ട് കുഴികൾക്കുള്ളിൽ CO_2 നിലനിർത്തുന്നതിനായി അടച്ചു വെച്ചു. എന്നും രാവിലെ മൂടികൾ മാറ്റി, ചെടികൾ സാധാരണ പോലെ വളരുവാൻ അനുവദിച്ചു. ജൈവ വസ്തുക്കൾ നിരത്തിയ ട്രീറ്റ്മെന്റുകളിൽ എല്ലാം തന്നെ കൂടിയ CO_2 ബഹിർഗമനം അളന്നു. ഏറ്റവും അധികമായി കണ്ടത് ആദ്യ രണ്ടു ആഴ്ച്ചക്കുള്ളിലും അതിനു ശേഷം ക്രമേണ അളവ് കുറയുകയുണ്ടായി. മണ്ണിലെയും അന്തരീക്ഷത്തിലെയും താപനില തുറസ്സായ സ്ഥലത്തേക്കാളും താരതമ്യേന കൂടുതലായിട്ടാണ് കുഴികൾക്കുള്ളിൽ രേഖപ്പെടുത്തിയത്. രണ്ടു വർഷങ്ങളിലും കുഴികളിലെ ചെടികളിൽ ഒരു ട്രീറ്റ്മെന്റിലും കിഴങ്ങുകൾ ഉണ്ടായില്ല. സമൃദ്ധീകരണം വഴി ഉയർന്ന കാർബൺ ഡൈഓക്സൈഡിന്റെ അളവ് കിഴങ്ങുകൾ ഉണ്ടാവുന്നതിനു പകരം ഇലകളും കാണ്ഡവും തഴച്ചു വളരുന്നതിനാണ് സഹായകമായത്. അതിനാൽ ഉയർന്ന CO_2 അളവ് കൂർക്കയിൽ കിഴങ്ങുകൾ രൂപപ്പെടുന്നതിനു പ്രതികൂലമാണെന്നാണ് പഠനത്തിൽ നിന്നും തെളിഞ്ഞത്.