STANDARDIZATION OF AGROTECHNIQUES IN SPINACH BEET (*Beta vulgaris* L. var. *bengalensis*)

SRUTHY A B

(2018-11-014)

DEPARTMENT OF AGRONOMY

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM – 695 522

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by

SRUTHY A B

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2020

DECLARATION

I, hereby declare that this thesis entitled "**STANDARDIZATION OF AGROTECHNIQUES IN SPINACH BEET (*Beta vulgaris* L. var. *bengalensis*)**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani

Date: 20·08·20

Sruthy A B

(2018-11-014)

CERTIFICATE

Certified that this thesis entitled "**STANDARDIZATION OF AGROTECHNIQUES IN SPINACH BEET (*Beta vulgaris* L. var. *bengalensis*)**" is a record of bonafide research work done independently by Ms. Sruthy A B (2018-11-014) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellayani

Date: 20 . 08 . 2020

Dr. Sheeba Rebecca Isaac
(Major Advisor, Advisory Committee)
Professor
Department of Agronomy
College of Agriculture, Vellayani,
Thiruvananthapuram

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Sruthy A B (2018-11-014) a candidate for the degree of **Master of Science in Agriculture** with major in Agronomy, agree that this thesis entitled **"STANDARDIZATION OF AGROTECHNIQUES IN SPINACH BEET (*Beta vulgaris* L. var. *bengalensis*)"** may be submitted by Ms. Sruthy A B (2018-11-014), in partial fulfillment of the requirement for the degree.

Dr. Sheeba Rebecca Isaac
(Chairman, Advisory Committee)
Professor
Department of Agronomy
College of Agriculture, Vellayani,
Thiruvananthapuram

Dr. Shalini Pillai P.
(Member, Advisory Committee)
Professor and Head
Department of Agronomy
College of Agriculture, Vellayani
Thiruvananthapuram

Dr. Ameena M.
(Member, Advisory Committee)
Assistant Professor
Department of Agronomy
College of Agriculture, Vellayani
Thiruvananthapuram

Dr. Radhika N. S.
(Member, Advisory Committee)
Assistant Professor
Department of Plant Pathology
College of Agriculture, Padanakkad
Kasargode

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LIST OF ABBREVIATIONS

AMF	-	Arbuscular Mycorrhizal Fungi
ANOVA	-	Analysis of Variance
Ca	-	Calcium
CD	-	Critical difference
cfu g^{-1}	-	Colony forming unit
cm	-	centimetre
cm^2	-	centimetre square
DAT	-	Days after transplanting
dS m^{-1}	-	deci Siemens per metre
EC	-	Electrical conductivity
DM	-	Dry matter
DMP	-	Dry matter production
et al	-	Co-workers
Fe	-	Iron
Fig.	-	Figure
FYM	-	Farmyard manure
g	-	Gram
g L^{-1}	-	gram per liter
g m-^{2}	-	gram per square meter
ha^{-1}	-	per hectare
i.e.	-	That is
IST	-	Indian Standards Time
K	-	Potassium
KAU	-	Kerala Agricultural University
kg	-	kilo gram
kg ha-1	-	kilo gram per hectare
k lux	-	kilo lux

LAD	-	Leaf area index
LAI	-	Leaf area duration
mg	-	milli gram
mg 100 g^{-1}	-	milli gram per 100 g
mL	-	milli liter
MAS	-	Months after sowinng
MOP	-	Muriate of potash
N	-	Nitrogen
OD	-	Optical density
P	-	Phosphorus
pH	-	Negative logarithm of hydrogen ion concentration
q ha^{-1}	-	Quintals per hectare
RDF	-	Recommended dose of fertilizers
RH	-	Relative humidity
SEm	-	Standard error of mean
spp.	-	Several species
t	-	Tonnes
t ha^{-1}	-	Tonnes per hectare
UV	-	Ultra Violet
Var.	-	Variety
viz.	-	Namely
WAS	-	Weeks after sowing

LIST OF SYMBOLS

@	-	At the rate of
ºC	-	Degree Celsius
=	-	equal to
>	-	greater than
×	-	Multiplication
-	-	Minus
%	--	Per cent
±	-	Plus- minus sign
+	-	Plus (and)
/	-	Or
₹	-	Rupees

INTRODUCTION

1. INTRODUCTION

The exigency of nutritional security and dietary diversity for good health has necessitated the consumption of a wide range of food categories in the right quantities. Vegetables play a significant role in ensuring nutritional security, being embodiments of vitamins, minerals and phytochemicals. Among the broad group of vegetables, leafy greens are of paramount importance in providing succulent leaves and stem throughout the year. These are often termed 'nutritional powerhouses' being rich sources of proteins, minerals, vitamins, essential fatty acids and dietary fibre. In spite of the health benefits, the average coption of leafy vegetables is only 24 g per day (NNMB, 2012), against the recommended per day dietary allowance of 100 g (ICMR, 2011). This calls for an increased production of the leafy vegetables in the country. Increased production can be achieved either by increasing the area under cultivation, or by improving the productivity adopting improved management practices. Another option would be to popularize newer crops that show agro climatic suitability and have consumer acceptance.

Spinach beet or palak (*Beta vulgaris* L. var. *bengalensis*) is valued for its tender, soft and succulent leaves that are used as vegetable. It is regarded as the cheapest and the richest source of calcium (Ca), iron (Fe), phosphorus (P) and other minerals. It is also rich in proteins, fat, vitamins (C, D, E, K), antioxidants and fibre, which provides the necessary roughage in diet with a lacerative effect. Apart from its nutritional importance, spinach beet is valued for its medicinal properties and used for the treatment of inflammation, headache, paralysis and liver diseases (Bharad *et al*., 2013). The potential of spinach beet to yield a high biomass within a short span economically makes it a prospective green leafy vegetable for commercialization especially under protected conditions.

Even though spinach beet is grown widely in states like West Bengal, Punjab, Rajasthan, Maharashtra in India, the crop is a new introduction in Kerala and is presently becoming popular, particularly in the urban households. Research on the agrotechniques for commercial cultivation in the state are meagre. Works are limited to varietal suitability for open and protected conditions, standardization of the nutrient dose (Alur, 2017), farm trials on the varietal introduction, technology gap assessment and suitability of the crop for rain shelter cultivation were attempted (Meena *et al.*, 2016).

Among the different agrotechniques, maintenance of optimum planting geometry is a basic requirement to maximize yield and economic benefits from unit area. Increased plant population can increase the competition among plants for various growth factors and decrease yield while, a decreased population will undermine the efficiency of inputs. Hence, optimization of plant density becomes critical in enabling the crops to realize their genetic potential with efficient utilization of growth factors.

Nutrient management has significant influence on the leaf yields (Jha and Jana, 2009). In the present era of sustainable agriculture, the focus should be on producing more, ensuring soil health and satisfactory yields. In this backdrop, a comparison of organic and conventional nutrient management is relevant so as to study the effect of nutrient sources on yield, nutritional quality and soil properties.

Spinach beet is cultivated for its succulent leaves and tender stem and hence, the yield depends upon the vegetative growth. Cutting management is important as frequent harvests intensify vegetative growth by production of newer leaves. However, the number of harvests needs to be standardized for economic yields and quality.

Taking into account the upcoming popularity of spinach beet, its suitability for rain shelter cultivation and the need for standardization of agrotechniques for cultivation in Kerala, the present study was envisaged with the precise objectives

- to standardize the planting geometry, nutrient management practice and number of harvests for economic yield and quality in spinach beet under rain shelter conditions and
- to assess the effect on the chemical and biological properties of soil.

2. REVIEW OF LITERATURE

Leafy greens are regarded as “Mines of Minerals” being rich and cheap sources of Fe, Ca, vitamins, antioxidants, protein and fibre. Even though spinach beet is popular in northern states, it is a recent introduction in Kerala. Its high productivity, climatic suitability and short duration prove the vegetable to be a better alternative for the traditional amaranth and has scope for commercial cultivation. This calls for the standardization of package of practices for efficient and economic cultivation of spinach beet.

Among the agronomic management practices, planting geometry, nutrient management, cultural operations including weeding, irrigation, earthing up and time of harvest are crucial in realising the yield potentials of the cultivar. A review on the influence of spacing, nutrient management and number of harvests in spinach beet are described below. As research in spinach beet is meagre, those pertaining to other leafy vegetables, wherever relevant, are also included.

2.1 EFFECT OF SPACING

An optimum planting geometry is important for crops to realise their genetic potential. Singh *et al*. (1984) opined that the full yield potential of a plant can be attained only if the plants are adequately spaced. A decrease in plant spacing and a corresponding increase in population density will enhance the competition between plants for various growth factors leading to lowered yield and productivity.

2.1.1 Effect of Spacing on Growth and Yield

Bracy *et al.* (1991) recorded increased yields in spinach and cabbage with closer spacings and increase in number of rows per unit area. In cabbage, Ghati *et al.* (1992) documented the highest number of marketable heads and yields with a closer spacing of 30 cm between rows.

Leskovar *et al*. (2000) reported higher values for the growth parameters, leaf area and plant height in spinach when planted at 15 cm spacing compared to those at

25 cm spacing. The fresh yield was 42 per cent greater than that in the wider spacing. Waseem *et al.* (2000) stated that row spacing in spinach plants had no significant influence on plant height and number of leaves per plant, but, green leaf yield and dry matter production (DMP) varied significantly.

Among the three plant to plant spacings (15 cm, 30 cm and 45 cm), explored in spinach beet the highest green yield was obtained with 15 cm, whereas highest per plant yield was realized in the 45 cm spaced plants (Mane *et al.*, 2008).

Gimplinger *et al.* (2008) reported that there was significant reduction in plant height in grain amaranth with increase in plant density. Maboko and Du Plooy (2009) documented maximum values of yield and yield components in lettuce with the closest spacing of 20 cm x 10 cm.

According to Yarnia (2010), optimum yields can be attained only if the plant community produces enough leaf area to provide maximum radiation interception, minimizing the inter plant competitions. In his study in amaranthus, he found that plant growth in terms of height decreased by 20.78 per cent with increase in plant density from 30 plants m^{-2} to 40 plants m^{-2}.

In water leaf, Uko *et al.* (2013) recorded that the plants were vigorous when widely spaced, but the fresh and dry matter yield per unit area were less compared to that of closely planted crops due to the higher plant population in the latter.

The effects of sowing time and plant spacing were evaluated in water spinach by Sarkar *et al.* (2014b) and they concluded that early sowing with closer spacing (30 cm x 15 cm) produced the highest green yield, nearly 3.26 times more than that in 30 cm x 45 cm spacing. Awan *et al.* (2016) reported that plant spacing had no significant effect on plant height, number of leaves per plant and biomass production in spinach.

Tiwari *et al.* (2016) opined that in fenugreek, with increase in row spacing, the growth parameters, plant height and number of branches per plant, increased significantly. However, yield and biomass production were higher in the closer spacing.

In spinach beet, Aakanksha and Anjali (2017) reported the significant influence of spacing on plant height, stem girth and growth. Among the spacings tried, closer spacing (15 cm) produced the highest fresh yield (108.07 q ha^{-1}) whereas wider spacing (45 cm) gave the maximum per plant yield (39.10 g).

2.1.2 Effect of Spacing on Nutrient Uptake and Quality

The quality of leafy vegetables is affected by its genetic potential as well as external factors like environmental conditions and agronomic management. All agrotechniques evolved aim to maximize the yield of good quality leaves. Plant population is one of the factors that decides the quality in terms of nutrient, chlorophyll and vitamin content of leaves (Ragoobarsingh, 1990).

Ramachandra (1990) reported that the wider spacing of 60 cm x 15 cm in grain amaranth resulted in the lowest Nitrogen (N) uptake and Anand (2000) illustrated the highest N uptake with closer spacing of 30 cm x 15 cm.

Leskovar *et al*. (2000) opined that with increase in plant population, the quality of the foliage of spinach increased when all the management practices were adopted at its optimum. Maximum leaf protein content in amaranth was obtained when the plants were widely spaced which was three times that of the closely planted crops (Yarnia, 2010).

Similar reports have been documented by other workers in other leafy vegetables. Mujahid and Gupta (2010) reported higher leaf chlorophyll, carotenoid and vitamin C content in lettuce leaves when grown with a wider spacing of 60 cm x 45 cm. In kale, the leaf quality parameters *viz.*, total chlorophyll content (61.06 mg $100g^{-1}$), total carotenoids (2.53 mg 100 g^{-1}) and vitamin C content (100.65 mg $100g^{-1}$) were found to be higher when grown under wider spacing of 30 cm x 40 cm (Naik and Gupta, 2010). Innocent (2014) concluded that the decrease in leaf chlorophyll content in leafy vegetables associated with increased plant density was due to mutual shading and increased competition for growth factors. Wider spacing offered lesser competition between water spinach plants for nutrients (Sarkar *et al*., 2014b) and hence could accumulate more vitamin C and carotenoid contents in leaves. It also resulted in increased nitrate accumulation in leaves.

The effect of spacing (15 cm, 30 cm and 45 cm) on quality of spinach beet was investigated by Aakanksha and Anjali (2017) and it was reported that the nutrient content and chlorophyll were the highest when the plants were grown 45 cm apart.

2.2 EFFECT OF NUTRIENT MANAGEMENT PRACTICES

Spinach beet with an indeterminate growth habit offers scope for multiple harvests and requires comparatively higher amounts of nutrients which should be supplied through external inputs in a judicious manner. Among the nutrients, N is crucial for vegetative growth and Cantliffe (1992) reported that spinach beet is highly fertilizer responsive. The nutritional quality of the leaves also depends on the dose and the source of nutrients.

2.2.1 Effect of Nutrient Management on Growth and Yield

The positive response of spinach beet to nutrient application has been reported by several authors (Jana *et al*. 1999; Singh *et al*., 2015).

Alur (2017) reported that the nutrient dose of 80: 40: 80 kg NPK ha^{-1} was ideal for open and protected cultivation of spinach beet, the yields being 6.7 and 1.3 per cent higher than the lowest dose of 40: 20: 40 kg NPK ha^{-1}.

Giardini *et al.* (1992) and documented higher yields in spinach with poultry manure which was superior to chemical fertilizers. Lampkin (1994) reported 24.5 per cent more yield under conventional cultivation compared to plants grown under organic management. Preetha (2003) recorded higher yields per unit area with organic nutrient management in amaranthus during first and second harvests. Xu *et al*. (2003) illustrated that in leafy vegetables, although the initial growth of plants was low in organically grown crops, it increased later and recorded maximum total yields.

Padmanabha *et al*. (2008) reported that farmyard manure (FYM) and inorganic sources of nutrients @ 150: 100: 100 kg NPK ha^{-1} improved the growth and yield in spinach beet. Integrated use of organic and inorganic fertilisers was found better (Jha and Jana, 2009). They observed that the yield and quality parameters of spinach beet variety, All Green were significantly the highest with application of vermicompost @ 10 t ha^{-1} along with 10 per cent recommended dose of NPK.

Masarirambi *et al.* (2010) evaluated the effect of organic fertilizers on the growth, yield and quality in red lettuce and reported that sustainable growth of lettuce could be achieved with organic sources. Anuja and Jayalakshmi (2011) identified the combination of panchagavya 4 per cent + 100 per cent NPK (75:50:50 kg ha^{-1}) to be the best in spinach beet var. Ooty -1.

Dange *et al*. (2011) explored different integrated nutrient management practices in spinach beet and observed maximum growth and yield in terms of plant height, leaf area, leaf yield with 50 per cent recommended dose of fertilizers (RDF) in inorganic form and remaining 50 per cent RDF as poultry manure.

Caliskan *et al*. (2014) demonstrated the superiority of poultry manure over cattle manure and compost in lettuce.

2.2.2 Effect of Nutrient Management on Nutrient Uptake and Quality

Leafy vegetables require a balanced application of nutrients for proper growth, yield and quality. In spinach, Dhillon *et al.* (1987) illustrated the significant increase in uptake of N with successive increase in amount of N applied. It was also observed that the uptake of P and potassium (K) also increased significantly with the levels of N applied. Rathore and Manohar (1989) reported maximum N and P uptake by fenugreek fertilised with 20 kg N ha^{-1} and 75 kg P_2O_5 ha^{-1}. Panchal *et al.* (1991) and Malligawad (1994) reported increased nutrient uptake in amaranthus with higher doses of N.

Application of organic manures in the form of FYM along with the inorganic sources of nutrients enhanced the nutrient content as well as uptake in spinach beet (Padmanabha *et al.*, 2008). Later Rajeswari and Shakila (2010) also reported organic nutrition to be the best for spinach beet, recording the highest nutrient uptake the sources being FYM @ 10 t ha^{-1} + vermicompost @ 2.5 t ha^{-1} + 3 per cent panchagaya as foliar spray. Studies on the nutrient uptake in Indian spinach (Islam *et al*., 2011) revealed integration of household wastes and reduced chemical fertilizers to record the highest N and K uptake.

According to Suresh *et al.* (1996), a well fertilized leafy vegetable crop will be highly productive and more nutritious on account of increased leaf protein content. Gent (2002) observed that nutrient content in foliage of lettuce, spinach, kale increased by 10 to 20 per cent with organic treatment compared to conventionally grown crops.

Plant nutrients, especially N and K, have significant roles in deciding yield and quality in spinach beet (Gairola *et al.*, 2009). They recommended N and K fertilizers in 1:1 ratio along with FYM in spinach beet for increased leaf area, dry weight, chlorophyll content, nitrate reductase activity and reduced nitrate content. Citak and Sonmez (2009) found that higher quantities of FYM and poultry manure could substitute the chemical fertilizers for higher yield and quality in spinach.

Lairon *et al.* (1984) had earlier reported that there was no significant variation in ascorbic acid content between organic and conventionally grown lettuce. On the contrary, Xu *et al.* (2003) observed that leaf quality attributes such as sugar content and vitamin C content were significantly higher and nitrate accumulation was found to be lower in organically grown crops compared to those under inorganic nutrition.

Increased nitrate contents with increased chemical fertilizer use were demonstrated in lettuce (Pavlou *et al.*, 2007; Liu *et al.*, 2014). On the contrary, the vitamin C content found to be maximum (7.63 mg 100 g^{-1}) in the organically grown lettuce plants with FYM as source of N compared to conventionally grown chemical fertilised plants (Caliskan *et al.*, 2014).

Application of vermicompost in combination with biofertilizers recorded the highest quality parameters in terms of leaf chlorophyll, dry matter (DM), ascorbic acid and crude fibre in spinach beet (Jabeen *et al.*, 2018).

2.3 EFFECT OF NUMBER OF HARVESTS

Yield of spinach beet depends on the vegetative growth, hence cutting management is important as frequent cutting encourages development of side shoots and ultimately increased yield (Singh and Gill., 1983).

2.3.1 Effect of Number of Harvests on Growth and Yield

Verma *et al.* (1992) explored the effect of cutting in spinach beet and revealed that green yield increased with number of harvests and maximum leaf yield was obtained at fourth harvest (337.94 kg ha^{-1}). Maity *et al.* (1999) reported significantly higher crop growth rate and leaf yield in spinach beet with three cuttings.

Mehta *et al.* (1995) reported that in fenugreek, leaf yield was the highest with two harvests compared to single cutting at 30 days after sowing (DAS). In coriander, Menon and Khader (1997) observed that cutting given at 50 DAS so as to remove 25 per cent of the leaves, resulted in significantly taller plants (38.3 cm). Waseem and Nadeem (2001) elucidated the increase in number of leaves per plant with the increase in cutting frequencies in spinach and Kasture *et al.* (2002) recorded maximum leaf yield in the third cutting.

Tiwari *et al.* (2002) studied the effect of different dates of sowing with different levels of harvests (0, 1, 2, 3, 4 and 5 harvests) in coriander and the results revealed that the number of primary and secondary branches and benefit cost ratio (BCR) were the highest with two cuttings.

According to Thapa and Maity (2004), cutting management is important for producing maximum fresh yield, DM, number of branches, number of leaves and stem in leafy vegetables and based on their study they concluded that with increase in number of harvests, the observed parameters of length of leaves, breadth of leaves decreased.

Patil and Naik (2004) documented that the increase in number of cuttings decreased the plant height in spinach beet and the decline was more with each subsequent harvest.

Datta *et al*. (2008) studied effect of cutting management on growth and yield of coriander and found that single cutting at 30 DAS had no significant effect on growth, but, two cuttings at 30 and 50 DAS produced maximum green yield. Guha *et al.* (2013) also opined that maximum green yield in coriander was obtained with two cuttings under protected cultivation.

Bharad *et al.* (2013) recorded maximum plant height and leaf area in spinach beet in the first harvest while maximum number of leaves and green yield were recorded in the third cutting. Increase in yield with increased number of harvests was reported in spinach beet by Singh *et al*. (2013) and according to the authors, maximum green yield was registered with three harvests. Singh *et al*. (2015) documented the maximum leaf yield (291.44 q ha^{-1}) with the third harvest followed by second harvest (270 q ha^{-1}). Narayan *et al*. (2018) recommended three cuttings and sowing in October for higher green yields in spinach beet.

2.3.2 Effect of Number of Harvests on Nutrient Uptake and Quality

The effect of various factors *viz.*, soil moisture, light intensity and stage of harvests on quality of spinach foliage in terms of oxalate content was studied by James (1972). The effect of environmental factors was found to be non significant as the oxalate content in plants is a genetically determined character.

Tomar (2001) reported that in spinach, the nutritional quality parameters (ascorbic acid and vitamin A content) were significantly influenced with cutting management and the quality was found to decrease with increase in number of harvests. Similar results were also documented by Thapa and Maity (2004).

Bharad *et al.*(2013) reported the highest chlorophyll content in the leaves of first harvest (1.91 mg g^{-1}) followed by those in second (1.68 mg g^{-1}) and third (1.51 mg g^{-1}) harvest.

Jyothi (2006) reported a decline in leaf protein content in spinach and amaranthus with successive harvests, the content in spinach being 29.74, 28.2, 26.23 per cent for first, second and third harvests, respectively.

2.4 INTERACTION EFFECTS ON GROWTH AND YIELD

2.4.1 Spacing x Nutrient Management

Ramachandra (1990) reported higher DMP in amaranthus with wider spacing of 60 cm x 15 cm along with 50 kg N ha^{-1} while leaf area index (LAI) was maximum with 30 cm x 15 cm spacing and 40 kg N ha^{-1}.

Delchev (1999) reported the highest fresh yield (50.9 t ha^{-1}) and DMP (8.4 t ha^{-1}) in amaranthus with closer spacing of 12.5 cm and 210 kg N ha^{-1}.

Anand (2000) studied the interaction effect of spacing and nutrient management in amaranthus and found that there was no significant interaction between fertilizers and spacing with respect to plant height, number of leaves and biological yield, however, the highest LAI was obtained with 30 cm x 15 cm spacing and 80: 80: 40 kg NPK ha^{-1}.

Raghavendra (2006) documented significantly taller plants with closer spacing of 30 cm x 15 cm combined with 125:50:50 kg NPK ha^{-1} and maximum number of leaves with closer spacing and 75:50:50 kg NPK ha^{-1}in amaranthus.

Significant interaction effects of row spacing and organic nutrition in coriander were reported by Vasmate *et al.* (2007) and the combination of 30 cm x 20 cm spacing with FYM (20 t ha^{-1}) was found best in terms of growth attributes *viz*., plant height, number of branches and leaf spread.

Diwan *et al.* (2018) studied the effect of row spacing and N in coriander and reported the highest growth parameters (plant height, number of branches and DMP) were recorded in 90 kg N ha^{-1} and wider row spacing of 50 cm x 10 cm.

2.4.2 Spacing x Number of Harvests

The impact of row spacing and cuttings on vegetable amaranth (*Amaranthus* spp.) revealed that green yield increased over successive harvests with the increase in spacing (Mortley *et al.*, 1992). Norman and Sichone (1993) explored the response of amaranth to the time of harvesting, spacing and frequency of harvesting and concluded that early topping (two weeks after planting) reduced the yield as well as the leaf : stem ratio, the closer spacing of 45 cm × 45 cm recorded the lowest total yield per plant, but, the highest total yield ha^{-1}.

According to Waseem and Nadeem (2001), row spacing and number of harvests significantly influenced the fresh yield and DMP in spinach and reported that closer spacing by broad casting and three cuttings independently resulted in maximum fresh yield (2157.59 and 2329.44 kg ha^{-1}) and DMP (212.37 and 221.61 kg ha^{-1}) respectively.

Maboko and Du Plooy (2013) analysed the interaction effect of plant density and cutting interval in swiss chard and documented that the number of leaves, leaf area, fresh yield and DMP were maximum with 40 plants m^{-2} and harvesting interval of 14 days compared to the plant densities of 50, 40, 25, 16 and 10 plants m^{-2} and harvesting frequencies of 7, 14 and 21 days.

The effects of three spacings (15, 30 and 45 cm) and four cuttings such (zero, once, twice and thrice) were studied in palak by (Mane *et al.*, 2008). The highest green leaf yield (10.89 t ha^{-1}) was reported with a spacing of 15 cm between plants whereas per plant yield (39.1 g) was highest with wider spacing of 45 cm. The third cutting recorded the maximum green yield per plant (67.92 g). The interaction of three cuttings and 15 cm spacing registered the highest green yield (19.79 t ha^{-1}).

In coriander, significantly higher green yields were obtained when grown at a spacing of 20 cm x 20 cm and harvested thrice (Nandal *et al.*, 2010).

2.4.3 Nutrient Management x Number of Harvests

Maity *et al.*(1999) analysed leaf production in *rabi* grown spinach beet harvested once, twice or thrice (30, 50 and 80 DAS), along with 50, 100 or 150 kg N ha^{-1} and reported the highest green leaf yield (197.82 q ha^{-1}) in the combination of 150 kg N ha^{-1} and three cuttings.

The effect of different levels of N, *viz.*, 30, 40 and 50 kg ha^{-1} and 40 and 60 kg P_2O_5 ha^{-1} with three levels of cuttings were studied by Thapa and Maity (2003) in fenugreek variety, Pusa Early Bunching. It was found that green yield was the highest with two cuttings and 50 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1}, while two cuttings with 45 kg N (Datta *et al.*, 2008) were reported best and 100 kg N (Dahiya *et al.*, 2009).

Naik *et al.* (2010) also observed maximum number of leaves plant^{-1} in spinach beet with vermicompost application and three cuttings. Singh *et al*. (2015) documented maximum green yield (270 q ha^{-1}) with 90 kg N ha^{-1} and two harvests. Nayak and Maji (2018) recorded maximum plant height with vermicompost application and two cuttings, whereas number of leaves harvested was found to be maximum with three cuttings and vermicompost application.

2.4.4 Spacing x Nutrient Management x Number of Harvests

Nandal *et al*. (2010) studied the effects of row spacing, P dose and number of harvests in coriander. The treatments included combinations of two spacing (20 cm x 20 cm and 40 cm × 10 cm), three levels of P (25, 50 and 75 kg P_2O_5 ha $^{-1}$) and three number of cutting (no cutting, single cutting at 30 DAS, two cutting at 30 and 50 DAS). The highest green yield was obtained with application of 75 kg P_2O_5 ha $^{-1}$ at a spacing of 20 cm x 20 cm and two cuttings; however, seed yield was lowest for this treatment combination.

2.5 INTERACTION EFFECT ON NUTRIENT UPTAKE AND QUALITY

2.5.1 Spacing x Nutrient Management

Bhati and Shaktawat (1994) reported maximum crude protein (10.96 %) and essential oil (5.38 %) in coriander leaves when fertilized with 60 kg N ha^{-1} under closer spacing.

Naruka *et al.* (2012) studied the response of ajowan (*Trachyspermum ammi*) to different N doses and spacing and reported significantly higher quality of the foliage (chlorophyll and carotenoid content) with 60 kg N ha^{-1}and wider spacing of 45 cm x 30 cm.

The influence of different levels of nutrients and spacing on the yield and chlorophyll content in spinach beet was studied by Chakraborty *et al*. (2015). The N dose of 90-120 kg ha^{-1} and 30 cm row spacing produced foliage with highest chlorophyll content.

2.5.2 Spacing x Number of Harvests

Literature on the interaction effects of spacing and number of harvests on quality in leafy vegetables is scanty. Basra *et al.* (2015) studied effect of planting density and cutting frequency on the nutritional quality in *Moringa oleifera* and reported significant effect of the interaction on N, K and ascorbic acid content in leaves with wider spacing and longer cutting intervals recording superior values.

2.5.3 Nutrient Management x Number of Harvests

Jyothi (2006) reported that in amaranthus and spinach, the leaf NPK content decreased with successive harvests and the chemical fertilizer application resulted in higher nutrient content of leaves.

The research results of Bharad *et al*. (2013) and later Sharma and Agarwal (2014) support the findings that vermicompost application and two cuttings recorded the highest ascorbic acid content in leaves of spinach beet. Nayak and Maji (2018) reported maximum ascorbic acid content in spinach beet with vermicompost application and two harvests, but the chlorophyll content was higher with urea application and single harvest.

In the experiment to determine the effect of number of harvests and N doses on growth, yield and quality of water spinach, Sarkar *et al*. (2014a) found that the single cutting done at 45 DAS with 150 kg N ha^{-1}recorded the highest vitamin A, while ascorbic acid content (45.31 mg 100 g^{-1}) and the lowest leaf nitrate content (401.0 mg kg^{-1}) were registered with single cutting without addition of N fertilizers.

Singh *et al*. (2015) documented the significantly highest leaf yield and ascorbic acid content in spinach beet with application of N @ 90 kg ha^{-1} and two cuttings.

2.6 EFFECT ON SOIL PROPERTIES

Available literature on the effect of spacing and repeated harvests on soil properties in the cultivation of leafy vegetables are not many. However, the variations in soil chemical and biological properties with nutrient management practices have been documented.

Alur (2017) reported non significant variations in soil properties with varieties in spinach beet, whereas the soil pH and available NPK content of soil increased with nutrient dose, and the highest values were for the NPK dose of 80: 40: 80 kg ha^{-1}.

The improvement in soil chemical and biological properties with organic manure application as nutrient sources have been reported by many authors (Bano *et al*., 1987; Madhavi, 1992). Islam *et al.* (2017) reported significant improvement in soil pH and EC with organic manure application in tomato.

Mekha (2013) reported integrated use of organic manures and chemical fertilizers *viz.,* oil cake + rock phosphate + wood ash for higher available N and K and oil cake + bone meal + wood ash for available P in amaranthus.

Islam *et al*. (2011) reported the significantly highest available NPK content with poultry manure 2.5 t ha^{-1} along with 75 per cent RDF in Indian spinach.

Roy *et al*. (2009) studied effect of integrated nutrient management in spinach and opined significantly higher organic carbn (C) and available N content of soil with poultry manure @ 3t ha^{-1} and one third nutrient dose as chemical fertilizers.

Drinkwater *et al.* (1995) opined organic nutrition influenced fungal population and actinomycetes spore load more than conventional nutrition. According to Fraser (1988), the organic C status of soil is an indication of soil biological activity and soil health.

The effect of organic nutrition on soil biological properties was reported by Krishnakumar *et al.* (2005) and it was reported that organic nutrition resulted in significantly higher microbial population *viz.*, bacteria (38.6 x 10^{6} cfu g^{-1} soil), actinomycetes (12.2 x 10^{4} cfu g^{-1} soil) and fungi (15.2 x 10^{6} cfu g^{-1} soil) compared to control.

Jyothi (2006) reported that there was no significant variation in available NPK content of soil after harvest of amaranthus and spinach with organic sources *viz.*, FYM, vermicompost, poultry manure; however, the nutrient availability of soil was comparatively higher for control plots manured with chemical fertilizers.

Bahadur *et al.* (2012) reported integrated nutrient management using FYM, fertilizers and biofertilizers to be best for soil microbial growth. Studies on the impact of long term organic and inorganic nutrient management practices by Chinnadurai *et al.* (2014) emphasized the importance of organic nutrition in the maintenance of soil biological properties. Harishma (2015) reported higher counts of soil bacteria and fungi (67.8 x 10^{6} and 4.7 x 10^{4} cfu g^{-1} soil respectively) using vermicomposted coconut leaves in amaranthus.

The above cited literature reveals that plant density, nutrient sources and cutting management are critical management practices that decides the yield, quality of produce and soil properties in leafy vegetables. However the research reports pertaining to above aspects in spinach beet especially under protected conditions are meagre. Hence, the present investigation was undertaken as an attempt to standardize spacing, nutrient management and number of harvests in spinach beet under rain shelter condition.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The field experiment on "Standardisation of agrotechniques in spinach beet (*Beta vulgaris* L. var. *bengalensis*)" was carried out at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala to standardize the planting geometry, nutrient management practice and number of harvests for spinach beet under rain shelter condition and to assess the effect on the chemical and biological properties of soil.

A concise description of materials used and methods adopted for the research work are given below.

3.1 EXPERIMENTAL SITE

The experiment was conducted under rain shelter condition in the crop museum attached to the Department of Agronomy, College of Agriculture, Vellayani. The site is situated at 8.5^{o} N latitude, 76.9^{o} E longitude and at an altitude of 29 m above mean sea level.

3.1.1 Soil

The soil of the experimental field belongs to the soil order oxisols with sandy loam texture. Samples were taken from different points in the field at a depth of 0-20 cm and pooled to get a representative sample for analysis. The chemical and biological properties assessed before the layout of the experiment are furnished in Table 1.

3.1.2 Climate and Season

The experiment was conducted during October 2019 to January 2020 and the meteorological data recorded at 7.22 h and 14.22 h during the cropping season collected from the Department of Agricultural Meteorology, College of Agriculture, Vellayani are documented in Appendix 1 and presented in Fig. 1.

3.1.3 Previous Cropping History

The experimental area was cultivated with vegetables in rotation and during the previous cropping season, coleus was raised for production of vine cuttings

Table 1. Chemical and biological properties of soil before the experiment

Sl. No.	Parameters	Content in soil and status	Method used
A.	**Chemical properties**		
1.	Soil reaction (pH)	5.89 (medium acidic)	pH meter with glass electrode (Jackson, 1973)
2.	Electrical Conductivity (dS m^{-1})	0.29 (normal)	Digital conductivity meter (Jackson,1973)
3.	Organic C (%)	1.08 (medium)	Walkley and Black rapid titration method (Jackson,1973)
4.	Available N (kg ha^{-1})	202.32 (low)	Alkaline permanganate method (Subbiah and Asija,1956)
5.	Available P (kg ha^{-1})	45.5 (high)	Bray colorimetric method (Jackson, 1973)
6.	Available K (kg ha^{-1})	129.92 (medium)	Ammonium acetate method (Jackson,1973)
B.	**Biological properties**		
1.	Microbial count (cfu g^{-1} soil)		
A	Bacteria	41.0 x 10^6	(Timonin,1940)
B	Actinomycetes	2.3 x 10^4	
C	Fungi	3.8 x 10^3	

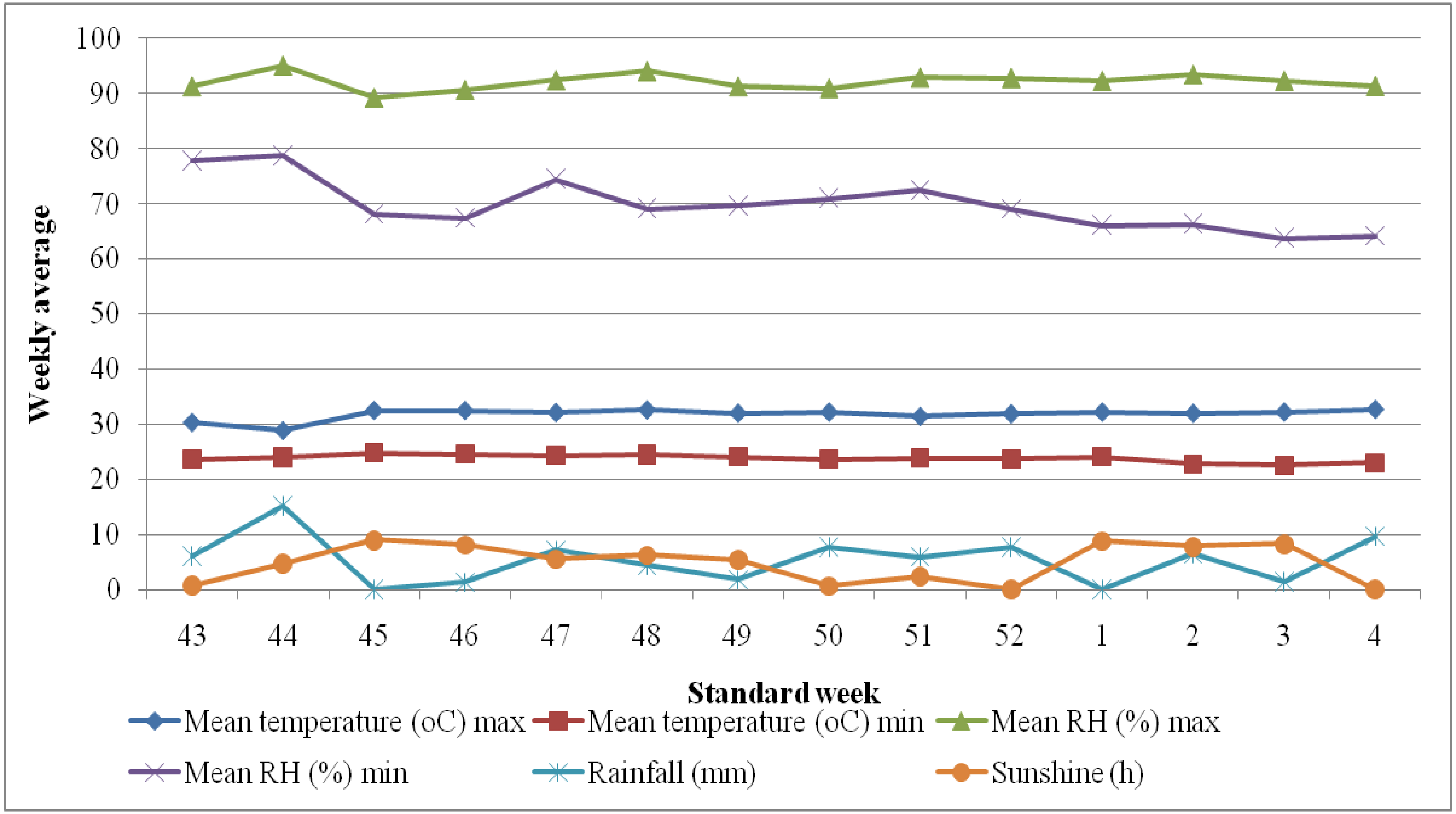

Fig. 1 Weather data during the cropping period (22 October 2019- 28 January 2020)

3.2 MATERIALS

3.2.1 Details of the Protected Structure

The experiment was conducted in the naturally ventilated polyhouse (260 m^2 area) which is saw toothed in structure with the frame work made of GI pipes and roof cladding with 200 micron UV stabilized polythene sheet. The sides of polyhouse were open, except for an agro shade net of green colour covering to a height of 2 m from the ground, to prevent the entry of stray dogs in the field.

3.2.2 Crop and Variety

Spinach beet variety used for the study was All Green, released from Indian Agricultural Research Institute, New Delhi. All Green is a late variety suitable for *rabi* season and is characterised by 15 - 20 cm plant height, light green coloured stalks and leaves. Leaves are tender and succulent and on an average, 6 - 7 cuttings can be taken at 15 - 20 days interval. The average recorded yield of the variety is 12.5 t ha^{-1}. The seeds for the experiment were procured from National Seed Corporation, Palakkad, Kerala.

3.2.3 Manures and Fertilizers

The organic manure used in the experiment was FYM (0.48 % N, 0.18 % P_2O_5 and 0.5 % K_2O) procured from a local household in Vellayani. The nutrient sources used as per treatments included vermicompost (1.28 % N, 0.48 % P_2O_5 and 0.54 % K_2O), wood ash (6.03 % K_2O), chemical fertilizers, urea (46 % N), rajphos (20 % P_2O_5) and muriate of potash (MOP) (60 % K_2O). Vermicompost was prepared in the compost unit attached to the Department of Agronomy using banana waste and other crop residues, and wood ash was collected from college hostel. The biofertilizer, arbuscular mycorrhizal fungi (AMF) was procured from Department of Agricultural Microbiology, College of Agriculture, Vellayani.

3.3 METHODS

Design	:	Randomised Block Design
Treatments	:	12
Replications	:	3
Plot size	:	3.0 m x 1.5 m

Treatments

Factor A: Spacing (S)

s_1: 20 cm x 10 cm

s_2: 30 cm x 10 cm

Factor B: Nutrient management (N)

n_1: Inorganic sources

n_2: Organic sources

Factor C: Number of harvests (H)

h_1: 4 harvests

h_2: 5 harvests

h_3: 6 harvests

Treatment combinations:

T_1	-	$s_1n_1h_1$	T_2	-	$s_1n_1h_2$	T_3	-	$s_1n_1h_3$
T_4	-	$s_2n_1h_1$	T_5	-	$s_2n_1h_2$	T_6	-	$s_2n_1h_3$
T_7	-	$s_1n_2h_1$	T_8	-	$s_1n_2h_2$	T_9	-	$s_1n_2h_3$
T_{10}	-	$s_2n_2h_1$	T_{11}	-	$s_2n_2h_2$	T_{12}	-	$s_2n_2h_3$

3.3.2 Layout of the Field Experiment

The layout of the field experiment is depicted in Fig. 2

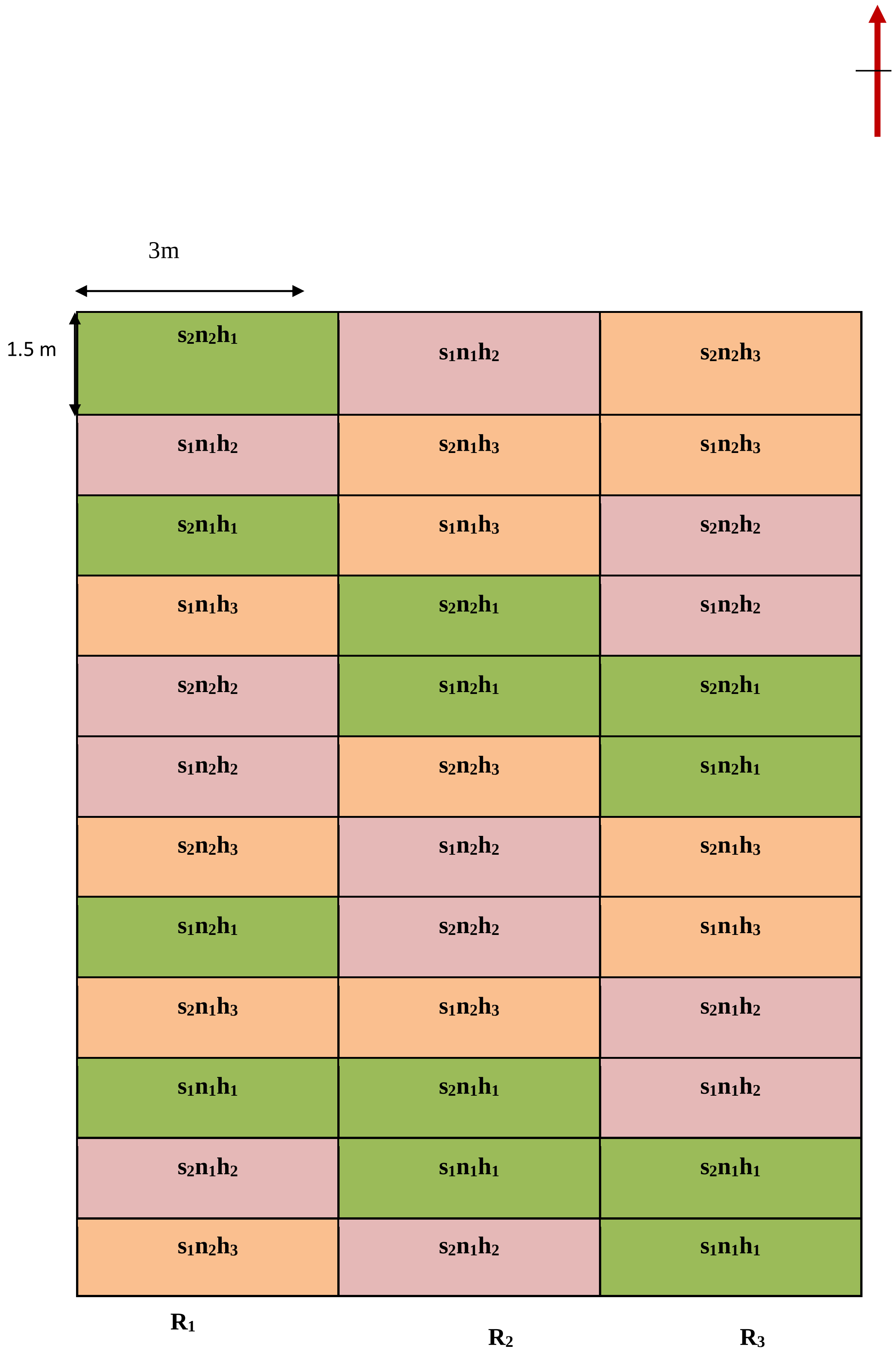

Fig. 2 Layout of the experimental field

Plate 1. General view of experimental field

3.3.3 Crop Management

The details of the various cultural operations done during the conduct of the experiment, from land preparation to final harvest, are as follows.

3.3.3.1 Land Preparation

The field was ploughed well using a power tiller and lime was incorporated @ 25 g m^{-2} based on soil test results. After ten days, the field was converted into raised beds of 3 m x 1.5 m size, with channels of 30 cm width in between. As a prophylactic measure against nematode infestation, neem cake was applied uniformly @ 50 g m^{-2}, prior to sowing.

3.3.3.2 Sowing of Seeds

Seeds were sown in the field @ 25 kg ha^{-1} after pre sowing treatment with 2 per cent *Pseudomonas fluorescens* solution for 12 hours. The crop was spaced as per the treatments fixed @ 20 cm x 10 cm (s_1) and 30 cm x 10 cm (s_2).

3.3.3.3 Gap Filling and Thinning

Gap filling was done one week after sowing (WAS) to ensure uniform plant population in the field. Later, the plots were thinned at 15 DAS, retaining two seedlings per hill.

3.3.3.4 Application of Manures and Fertilizers

The field was uniformly manured with FYM @ 10 t ha^{-1}. Nutrient dose of 80: 40: 80 kg NPK ha^{-1} (Alur, 2017) was adopted for nutrient management and organic and inorganic sources were given in respective plots as per the treatments fixed. One fourth of N and K, and full P were applied as basal dose, remaining N and K in equal splits as top dressing, 20 DAS, after first harvest (40 DAS) and second harvest (60 DAS), using organic and/ inorganic sources. AMF was applied @ 5 g mixture with dried FYM per pit prior to sowing in the organic nutrient management treatments.

3.3.3.5 Irrigation

The crop was raised in the rain shelter and hence was irrigated daily to ensure sufficient moisture in the beds.

3.3.3.6 Weeding and Earthing up

Weeding was done regularly to maintain the field weed free; earthing up, one month after sowing (MAS) and after each harvest.

3.3.3.7 Pest and Disease Management

Plant protection measures were taken as and when pest and disease incidence was noticed as per the recommendations. Prophylactic measures of seed treatment and soil drenching with *Pseudomonas fluorescens* @ 20 g L^{-1} were adopted against wilt incidence. Heavy rains coincided with the seedling stages and the high relative humidity (RH) within the rain shelter necessitated spot application of copper oxy chloride in soil @ 2 g L^{-1}. The leaf webber damage noticed was managed with the neem oil (5 per cent) spray given after the second leaf cutting and thereafter *Beauveria bassiana* was applied @ 20 g L^{-1} twice, at fortnight interval.

3.3.3.8 Harvest

The leaves were harvested when they were uniformly green, turgid and fully open, while the smaller ones were retained for later harvests. The crop was ready for the first harvest at 40 DAS and thereafter, harvests were done at 60, 70, 80, 95 and 105 DAS. As per the treatments, at final harvest, the plants in each treatment were uprooted, and roots and leaves separated for recording the observations.

3.4 OBSERVATIONS

Five representative plants were randomly selected from the net plot area avoiding the border rows and labelled as observation plants. The observations on the growth, yield attributes at specific intervals and leaf yields were recorded on these plants. Leaf area measurement was done on another six plants tagged for destructive sampling.

3.4.1 Growth and Growth Attributes

3.4.1.1 Plant Height

Plant height was measured from the base to the topmost growing tip of the observation plants at 30 DAS and at each harvest and the mean height at each stage was expressed in cm.

3.4.1.2 Leaf Area

Total leaf area of the observation plants tagged for destructive sampling were measured using graph paper method at each harvest and expressed in cm^2 per plant.

3.4.1.3 Leaf Area Index (LAI)

The leaf area computed was used to calculate the LAI at first, third and final harvests in each treatment using the formula developed by Watson (1947).

$$\text{LAI} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Land area occupied by the plant (cm}^2\text{)}}$$

3.4.1.4 Root Depth

Root depth was measured at final harvest as length of the longest root from the base of the stem to the root tip and expressed in cm.

3.4.1.5 Root Volume

Root volume was measured by the volume displacement method as equivalent to the volume of water displaced while immersing the roots of spinach beet in a measuring cylinder containing known volume of water, in accordance with the method described by Novoselov (1960).The root volume was expressed as mL.

3.4.2 Yield and Yield Attributes

3.4.2.1 Number of Leaves Harvested per Plant

The number of leaves harvested at each picking in the observation plants was counted and added to get the total number of leaves harvested per plant. The average of the observations was recorded in each replication.

3.4.2.2 Leaf Yield per Plant

The fresh weight of the leaves at each harvest in the observation plants were recorded and summed to get the total leaf yield per plant. The yield was expressed in g per plant.

3.4.2.3 Leaf Yield per 10 m²

The leaves harvested in each plot during every harvest were weighed and summed to compute the leaf yield per 10 m^2.

3.4.2.4 Dry Matter Production

Observation plants were uprooted, dried under shade and then in a hot air oven at 70 ± 5°C to a constant weight, and weighed to assess the total DMP in g per plant.

3.5 PLANT ANALYSIS

3.5.1 N P K Uptake by Crop

Fresh samples collected at the final harvest in each treatment were air dried and then oven dried at 70 ± 5^0C to a constant weight. The dried samples were finely ground and digested for estimation of NPK content. N content was estimated by the modified micro kjeldhal method (Jackson,1973), P content of diacid extract of samples determined colorimetrically using vanadomolybdo phosphoric yellow colour method (Jackson, 1973) and K using flame photometry method (Jackson, 1973). The nutrient contents were expressed in percentage and nutrient uptake by the crop was calculated using the formula,

Nutrient uptake = Nutrient content (%) x Total DMP (g per plant)

The uptake computed was expressed in g per plant.

3.5.2 Protein

Dried leaf samples at third and final harvests were digested using concentrated H_2SO_4 followed by distillation adopting the micro kjeldahl method for analyzing N content (Jackson, 1973). The protein content of leaves was calculated by multiplying N content of plant samples in per cent with the factor 6.25 (Simpson *et al.*, 1965).

3.5.3 Chlorophyll

The fully opened middle leaf in each plant at the third and final harvests was used for the estimation of chlorophyll content. The standard procedure of Hiscox and Israelstam (1979) was adopted for the estimation and optical density (OD) of the extract was read at 663 and 645 nm. The total chlorophyll content was calculated using the formula (Arnon, 1949) and expressed in mg g^{-1}.

$$\text{Total chlorophyll content} = \frac{20.2\ (OD_{663}) + 8.02\ (OD_{645}) \times \text{Volume of extract (mL)}}{1000 \times \text{weight of leaf sample (g)}}$$

3.5.4 Vitamin A

Freshly harvested leaves from the observation plants at third and final harvests were used for the estimation of vitamin A content as total beta carotene using colorimetric method of carotene estimation given by Sadasivam and Manickam (1996). The values were expressed in mg 100 g^{-1}.

3.5.5 Vitamin C

Vitamin C content was assessed in the freshly harvested leaves during third and final harvests adopting the 2, 6 – dichlorophenol indophenol dye method (AOAC, 1955).

3.6 SOIL ANALYSIS

3.6.1 Chemical analysis

Composite soil samples were collected after the completion of the experiment from individual plots of the experimental field, shade dried, cleaned and sieved using a 2 mm sieve for pH, EC, available N, P and K estimation and 0.5 mm sieve for organic C estimation. The analysis was done by adopting the standard procedures given in Table 1.

3.6.2 Microbial count

Rhizosphere soil was used for microbial enumeration using serial dilution - agar plating method (Timonin, 1940). The count of total bacteria, actinomycetes and fungi were taken with Nutrient Agar medium, Rose Bengal agar medium and Kenknights medium respectively (Johnson and Curl, 1972). The dilutions of 10^{-3} were used for isolation of fungi, 10^{-4} for actinomycetes, and 10^{-6} for bacteria.

The number of colonies in different plates were recorded and multiplied with its dilution factor to get the microbial count per gram of soil.

$$\text{Number of colony forming units (cfu)} = \frac{\text{Number of colonies x Dilution factor}}{\text{dry weight of soil}}$$

3.7 MICROCLIMATE

The weather parameters inside the rain shelter were recorded daily between 13:00 and 13:15 hours IST and the weekly average of standard weeks from 42nd of 2019 to 4th of 2020 were worked out.

3.7.1 Air Temperature

The air temperature was measured using digital thermo-hygrometer and expressed in ^{o}C.

3.7.2 Relative Humidity

Relative humidity was measured using digital thermo-hygrometer and expressed as percentage.

3.7.3 Soil Temperature

Soil temperature at a depth of 15 cm was measured using digital soil thermometer and expressed in ^{o}C.

3.7.4 Light Intensity

Lux meter HI 97500 was used to measure the light intensity at crop canopy level and expressed in k lux.

3.8 PEST AND DISEASE INCIDENCE

The pest and disease incidences during the cropping period were monitored.

3.9 ECONOMIC ANALYSIS

Economics of the spinach beet cultivation under the varied agrotechniques studied was assessed computing the cost of cultivation for each treatment and returns based on input cost, labour wages and prevailing market price of spinach beet.

3.9.1 Gross Income

Gross income was calculated by multiplying the leaf yield with unit price of spinach beet leaves**.**

Gross income (₹) = Total yield (kg) x Unit price (₹ kg^{-1})

3.9.2 Net Income

Net income was calculated by deducting the total cost incurred for the cultivation from the gross income. It was calculated for an area of 10 m^2 and expressed in ₹ $10m^{-2}$

Net income (₹$10\ m^{-2}$) = Gross income (₹) - Total cost of cultivation (₹)

3.9.3 Benefit: Cost Ratio (BCR)

The economic feasibility was assessed using BCR, which is the ratio of gross income and total expenditure

$$\text{BCR} = \frac{\text{Gross income}}{\text{Total cost of cultivation}}$$

3.10 STATISTICAL ANALYSIS

The data generated were subjected to statistical analysis using Analysis of Variance techniques (ANOVA) for 2 x 2 x 3 Factorial Randomised Block Design and the significance tested by applying ‘F’ test Snedecor and Cochran (1975). Wherever F test was found to be significant, the critical difference (CD) values were computed for treatment comparison.

RESULTS

4. RESULTS

The experiment entitled "Standardization of agrotechniques in spinach beet (*Beta vulgaris* L. var. *bengalensis*)" was carried out under rain shelter condition at College of Agriculture, Vellayani. The data recorded were statistically analyzed to assess the effect of spacing, nutrient management, number of harvests and their interactions on growth, yield and quality of spinach beet. The results obtained are detailed in this chapter.

4.1 GROWTH CHARACTERS

Plant growth observations were taken at 30 DAS and at different harvests of the crop.

4.1.1 Plant Height

The results on the effect of spacing, nutrient management, number of harvests and their interaction on plant height at 30 DAS and at each harvest [40 (first), 60 (second), 70 (third), 80 (final h_1), 95 (final h_2) and 105 (final h_3)] DAS are presented in the Tables 2a, 2b and 2c.

The effect of spacing was found to be significant at 30 DAS and at all the growth stages. Plants grown at 20 cm x 10 cm (s_1) spacing were significantly taller (17.81, 20.58, 32.66 and 38.30 cm) at 30 DAS, first, second and third harvest respectively, than plants at s_2 (30 cm x 10 cm) spacing. However, at final harvest, s_2 recorded significantly higher mean plant height of 33.64 cm.

Nutrient management influenced plant height significantly at all growth stages, except at third and final harvests. Plants grown with inorganic nutrient sources (n_1) were significantly taller with mean heights of 18.05, 19.99 and 32.34 cm at 30 DAS, first and second harvests respectively.

The influence of the number of harvests was significant only at the final harvest. Plants in h_1, in which harvesting was completed with the fourth harvest (80 DAS) were taller (33.99 cm) than the plants at the sixth harvest (h_3, 30.97 cm) but, on par with plants harvested five times (h_2), 32.59 cm.

Table 2a. Effect of spacing, nutrient management and number of harvests on plant height, cm

Treatments	30 DAS	First harvest (40 DAS)	Second harvest (60 DAS)	Third harvest (70 DAS)	Final harvest
Spacing (S)					
s_1 (20 cm x 10 cm)	17.81	20.58	32.66	38.30	31.40
s_2 (30 cm x 10 cm)	16.28	17.82	29.61	36.49	33.64
SEm (±)	0.46	0.66	0.41	0.36	0.61
CD (0.05)	1.334	1.933	1.215	1.046	1.790
Nutrient management (N)					
n_1 (inorganic)	18.05	19.99	32.34	36.89	33.34
n_2 (organic)	16.05	17.89	29.92	37.89	31.71
SEm (±)	0.46	0.66	0.41	0.36	0.61
CD (0.05)	1.334	1.933	1.215	NS	NS
Number of harvests (H)					
h_1 (four)	16.85	18.43	30.69	37.34	33.99
h_2 (five)	17.43	19.84	31.29	37.46	32.59
h_3 (six)	16.88	18.57	31.41	37.39	30.97
SEm (±)	0.56	0.81	0.51	0.44	0.75
CD (0.05)	NS	NS	NS	NS	2.193

DAS – Days after sowing

Table 2b. Interaction effects of spacing, nutrient management and number of harvests on plant height, cm

Interactions	30 DAS	First harvest (40 DAS)	Second harvest (60 DAS)	Third harvest (70 DAS)	Final Harvest
S x N Interaction					
s_1n_1	19.82	21.56	34.54	37.66	31.62
s_1n_2	15.80	18.56	30.77	38.94	31.18
s_2n_1	16.27	18.42	30.14	36.13	35.05
s_2n_2	16.30	17.24	29.04	36.86	32.29
SEm (±)	0.64	0.93	0.59	0.50	0.86
CD (0.05)	1.887	NS	1.719	NS	NS
S x H Interaction					
s_1h_1	17.92	19.24	32.29	38.57	32.06
s_1h_2	17.63	21.62	32.19	38.19	31.79
s_1h_3	17.88	19.31	33.50	38.14	30.35
s_2h_1	15.78	17.62	29.10	36.11	35.93
s_2h_2	17.21	18.05	30.39	36.72	33.39
s_2h_3	15.86	17.81	29.33	36.64	31.61
SEm (±)	0.79	1.14	0.72	0.62	1.06
CD (0.05)	NS	NS	NS	NS	NS
N x H interaction					
n_1h_1	18.48	19.03	30.99	37.62	34.60
n_1h_2	18.43	21.84	32.73	37.31	33.43
n_1h_3	17.23	19.10	33.30	35.76	31.98
n_2h_1	15.22	17.83	30.40	37.07	33.39
n_2h_2	16.42	17.83	29.84	37.60	31.75
n_2h_3	16.52	18.02	29.52	39.03	29.98
SEm (±)	0.79	1.14	0.72	0.62	1.06
CD (0.05)	NS	NS	NS	1.811	NS

DAS – Days after sowing

Table 2c. Effect of S x N x H interaction on plant height, cm

Treatment combinations	30 DAS	First harvest (40 DAS)	Second harvest (60 DAS)	Third harvest (70 DAS)	Final harvest
$s_1n_1h_1$	20.23	20.23	33.44	38.23	32.86
$s_1n_1h_2$	19.70	25.23	34.96	37.79	32.25
$s_1n_1h_3$	19.53	19.20	35.22	36.97	29.75
$s_1n_2h_1$	15.61	18.25	31.14	38.91	31.26
$s_1n_2h_2$	15.57	17.99	29.40	38.60	31.33
$s_1n_2h_3$	16.23	19.43	31.77	39.32	30.96
$s_2n_1h_1$	16.73	17.82	28.54	37.00	36.34
$s_2n_1h_2$	17.17	18.43	30.49	36.83	34.61
$s_2n_1h_3$	14.93	19.00	31.38	34.55	34.21
$s_2n_2h_1$	14.83	17.41	29.66	35.22	35.51
$s_2n_2h_2$	17.26	17.67	30.29	36.61	32.17
$s_2n_2h_3$	16.80	16.62	27.27	38.73	29.00
SEm (±)	1.11	1.61	1.02	0.87	1.50
CD (0.05)	NS	NS	NS	NS	NS

DAS – Days after sowing

Among the first order interactions, S x N showed significant influence on plant height at 30 DAS and 60 DAS. The interaction s_1n_1 recorded significantly taller plants (19.82 and 34.54 cm) at 30 and 60 DAS, respectively.

The N x H interaction, n_2h_3, recorded maximum plant height at third harvest, but on par with n_2h_2, n_1h_1 and n_1h_2. All other interactions *viz.*, S x H and S x N x H were non significant at all stages of observation.

4.1.2 Leaf Area

The main and interaction effects of spacing, nutrient management and number of harvests on leaf area at first, second, third and final harvests are presented in the Tables 3a, 3b and 3c.

The results showed that spacing had significant effect on leaf area at second (60 DAS) and final harvest stages. Wider spacing of 30 cm x 10 cm (s_2) recorded significantly superior leaf area at these stages (312.2 and 315.7 cm^2 per plant). Leaf area was found to be significantly superior for plants fertilized with inorganic nutrient source (n_1), the values being 302.0 and 445.1 cm^2 per plant at first and third harvest, respectively.

The influence of number of harvests showed significant effects at second and final harvest, h_3 recorded maximum leaf area at both stages and at third harvest, h_3 was on par with h_2.

Among the first order interactions, S x N interaction exerted significant variation in leaf area at the second harvest (Table 3b). Maximum leaf area (330.5 cm^2 per plant) was recorded for s_2n_1, wider spacing and inorganic nutrition, at par with s_2n_2. No marked variation was recorded with S x H interaction.

Nevertheless, N x H showed significant effect on leaf area at third and final harvest. At third harvest, inorganic nutrient management in combination with five harvests (n_1h_2) showed the highest per plant leaf area of 474.7 cm^2 which was at par with n_1h_1 (431.8 cm^2), n_2h_3 (430.5 cm^2) and n_1h_3 (428.8 cm^2), but, significantly superior to n_2h_1 (401.2 cm^2) and n_2h_2 (372.8 cm^2).

Inorganic nutrient sources in combination with six harvests (n_1h_3) registered significantly the highest leaf area of 394.8 cm^2 per plant at final harvest. The second order interaction effects were found to be non significant at all stages of observation.

4.1.3 Leaf Area Index

The influence of spacing, nutrient management, number of harvests and their interaction on LAI at first, third and final harvests are presented in the Tables 4a, 4b and 4c.

Perusal of the data revealed that the significant influence of spacing on LAI at all the stages of observation. LAI was found to be significantly superior for s_1, the values being 1.39, 2.10 and 1.46 at the different harvest stages.

The variations in LAI due to the nutrient management practice adopted were significant at the first (40 DAS) and third harvest (70 DAS) and non significant at the final harvest. Inorganic nutrient management (n_1) of the plants recorded significantly higher LAI (1.27 and 1.85 at first and third harvest, respectively) compared to organic nutrient management (n_2).

The effect of number of harvests on LAI was found to be significant only at final harvest. Plants harvested six times (h_3) recorded significantly superior LAI (1.47) at the final harvest compared to plants with five (h_2) and four (h_1) number of harvests.

Among the two factor interactions, N x H showed significant effect on LAI at third and final harvest stages. At third harvest, n_1h_2 recorded maximum LAI (1.97) which was on par with n_2h_3 (1.80), n_1h_3 (1.79) and n_1h_1 (1.78). At final harvest, n_1h_3 recorded the significantly highest LAI of 1.67 and it was least in n_2h_1 (0.90).

The second order interaction was found to be significant only at the final harvest stage, $s_1n_1h_3$, (20 cm x 10 cm, inorganic nutrient management and six harvests) recorded the highest LAI of 1.93 and significantly superior to all other interactions.

Table 3a. Effect of spacing, nutrient management and number of harvests on leaf area, cm^2 per plant

Treatments	Leaf area			
	First harvest (40 DAS)	Second harvest (60 DAS)	Third harvest (70 DAS)	Final Harvest
Spacing (S)				
s_1 (20 cm x10 cm)	277.3	284.9	420.8	292.0
s_2 (30 cm x10 cm)	262.2	312.2	425.8	315.7
SEm (±)	8.5	8.8	10.9	7.3
CD (0.05)	NS	25.91	NS	21.51
Nutrient management (N)				
n_1 (inorganic)	302.0	303.6	445.1	310.3
n_2 (organic)	237.5	293.6	401.5	297.4
SEm (±)	8.5	8.8	10.9	7.3
CD (0.05)	24.89	NS	32.00	NS
Number of harvests (H)				
h_1 (four)	254.7	276.0	416.5	270.8
h_2 (five)	275.2	298.5	423.8	284.2
h_3 (six)	279.4	321.2	429.7	356.6
SEm (±)	10.4	10.8	13.4	8.9
CD (0.05)	NS	31.73	NS	26.35

DAS – Days after sowing

Table 3b. Interaction effect of spacing, nutrient management and number of harvests on leaf area, cm^2 per plant

Interactions	First harvest (40 DAS)	Second harvest (60 DAS)	Third harvest (70 DAS)	Final harvest
S x N interaction				
s_1n_1	310.0	276.7	434.9	297.6
s_1n_2	244.7	293.1	406.7	286.4
s_2n_1	294.0	330.5	455.3	323.0
s_2n_2	230.3	294.0	396.3	308.3
SEm (±)	12.1	12.5	15.4	10.4
CD (0.05)	NS	36.64	NS	NS
S x H interaction				
s_1h_1	266.3	259.0	410.0	273.0
s_1h_2	284.3	290.0	419.0	268.3
s_1h_3	281.3	305.7	433.3	334.7
s_2h_1	243.0	293.0	423.0	268.5
s_2h_2	266.0	307.0	428.5	300.0
s_2h_3	277.5	336.7	426.0	378.5
SEm (±)	14.8	15.3	18.9	12.7
CD (0.05)	NS	NS	NS	NS
N x H interaction				
n_1h_1	273.3	273.7	431.8	252.67
n_1h_2	313.0	291.3	474.7	283.3
n_1h_3	319.7	345.7	428.8	394.8
n_2h_1	236.0	278.3	401.2	288.8
n_2h_2	237.3	305.7	372.8	285.0
n_2h_3	239.2	296.7	430.5	318.3
SEm (±)	14.8	15.3	18.9	12.7
CD (0.05)	NS	NS	55.42	37.26

DAS – Days after sowing

Table 3c. Effect of S x N x H interaction on leaf area, cm^2 per plant

Treatment combinations	First harvest (40 DAS)	Second harvest (60 DAS)	Third harvest (70 DAS)	Final harvest
$s_1n_1h_1$	280.7	247.3	412.7	237.3
$s_1n_1h_2$	324.0	266.7	463.3	268.7
$s_1n_1h_3$	325.3	316.0	428.7	386.7
$s_1n_2h_1$	252.0	260.7	407.3	308.7
$s_1n_2h_2$	244.7	313.3	374.7	268.0
$s_1n_2h_3$	237.3	295.3	438.0	282.7
$s_2n_1h_1$	266.0	300.0	451.0	268.0
$s_2n_1h_2$	302.0	316.0	486.0	298.0
$s_2n_1h_3$	314.0	375.3	429.0	403.0
$s_2n_2h_1$	220.0	286.0	395.0	269.0
$s_2n_2h_2$	230.0	298.0	371.0	302.0
$s_2n_2h_3$	241.0	298.0	423.0	354.0
SEm (±)	20.9	21.6	26.7	17.96
CD (0.05)	NS	NS	NS	NS

DAS – Days after sowing

Table 4a. Effect of spacing, nutrient management and number of harvests on LAI

Treatments	Leaf Area Index (LAI)		
	First harvest (40 DAS)	Third harvest (70 DAS)	Final harvest
Spacing (S)			
s_1 (20 cm x10 cm)	1.39	2.10	1.46
s_2 (30 cm x10 cm)	0.87	1.42	1.05
SEm (±)	0.04	0.04	0.03
CD (0.05)	0.115	0.129	0.096
Nutrient management (N)			
n_1 (inorganic)	1.27	1.85	1.28
n_2 (organic)	1.00	1.48	1.23
SEm (±)	0.04	0.04	0.03
CD (0.05)	0.115	0.129	NS
Number of harvests (H)			
h_1(four)	1.07	1.73	1.13
h_2 (five)	1.15	1.76	1.17
h_3 (six)	1.17	1.79	1.47
SEm (±)	0.05	0.05	0.04
CD (0.05)	NS	NS	0.118

DAS – Days after sowing

Table 4b. Interaction effect of spacing, nutrient management and number of harvests on LAI

Interactions	First harvest (40 DAS)	Third harvest (70 DAS)	Final harvest
S x N interaction			
s_1n_1	1.55	2.17	1.49
s_1n_2	1.22	2.03	1.43
s_2n_1	0.98	1.52	1.08
s_2n_2	0.77	1.32	1.03
SEm (±)	0.06	0.06	0.05
CD (0.05)	NS	NS	NS
S x H interaction			
s_1h_1	1.33	2.05	1.37
s_1h_2	1.42	2.10	1.34
s_1h_3	1.40	2.17	1.67
s_2h_1	0.81	1.41	0.90
s_2h_2	0.89	1.43	1.00
s_2h_3	0.92	1.42	1.26
SEm (±)	0.07	0.08	0.06
CD (0.05)	NS	NS	NS
N x H interaction			
n_1h_1	1.15	1.78	1.04
n_1h_2	1.31	1.97	1.34
n_1h_3	1.34	1.79	1.67
n_2h_1	1.00	1.68	0.90
n_2h_2	1.00	1.56	1.00
n_2h_3	1.00	1.80	1.26
SEm (±)	0.07	0.08	0.06
CD (0.05)	NS	0.223	0.166

DAS – Days after sowing

Table 4c. Effect of S x N x H interaction on LAI

Treatment combinations	First harvest (40 DAS)	Third harvest (70 DAS)	Final harvest
$s_1n_1h_1$	1.40	2.06	1.19
$s_1n_1h_2$	1.62	2.32	1.34
$s_1n_1h_3$	1.63	2.14	1.93
$s_1n_2h_1$	1.26	2.04	1.54
$s_1n_2h_2$	1.23	1.87	1.34
$s_1n_2h_3$	1.19	2.19	1.41
$s_2n_1h_1$	0.89	1.50	0.89
$s_2n_1h_2$	1.00	1.62	0.99
$s_2n_1h_3$	1.05	1.43	1.34
$s_2n_2h_1$	0.73	1.32	0.90
$s_2n_2h_2$	0.77	1.24	1.00
$s_2n_2h_3$	0.80	1.41	1.18
SEm (±)	0.09	0.12	0.08
CD (0.05)	NS	NS	0.235

DAS – Days after sowing

4.1.4 Root Depth

The influence of spacing, nutrient management, number of harvests and their interaction on root depth of plants at final harvest are depicted in Tables 5a, 5b and 5c.

The results showed that main effect and first order interactions had no significant effect on root depth whereas second order interaction was found to be significant. Spinach beet planted at the wider spacing, inorganic nutrient management and five harvests ($s_2n_1h_2$) recorded the highest rooting depth (21.39 cm), at par with $s_1n_1h_3$ (21.00 cm), $s_1n_2h_2$ (19.29 cm), $s_2n_2h_3$ (18.97 cm), $s_1n_2h_3$ (18.91 cm), $s_2n_1h_1$ (17.56 cm) and the lowest value was noted in $s_1n_1h_2$ (14.15 cm).

4.1.5 Root Volume

Tables 5a, 5b and 5c portray the main and interaction effects on root volume of plants at the final harvest. The results showed that the number of harvests alone had significant effect on root volume. It was the highest for plants left for six harvests (h_3, 5.02 mL) and on par with five (h_2), but significantly superior to four (h_1) harvests.

4.2 YIELD AND YIELD ATTRIBUTES

Variations in the total number of leaves harvested per plant and leaf yield are furnished in Tables 6a, 6b and 6c.

4.2.1 Number of Leaves Harvested per Plant

It is evident that the main effects of spacing, nutrient sources and number of harvests had significant effect on number of leaves harvested.

Individual effects of spacing and nutrient management on number of leaves harvested were significant and superior in the wider spacing (31.2) and inorganic nutrition (31.0). The number of leaves harvested was the highest in six harvests (33.5) followed by five (29.5) and significantly the lowest for four harvests (26.7).

Table 5a. Effect of spacing, nutrient management and number of harvests on root depth and volume

Treatments	Root depth (cm)	Root volume (mL)
Spacing (S)		
s_1 (20 cm x10 cm)	17.46	4.20
s_2 (30 cm x10 cm)	17.53	4.28
SEm (±)	0.70	0.35
CD (0.05)	NS	NS
Nutrient management (N)		
n_1 (inorganic)	17.52	4.00
n_2 (organic)	17.48	4.48
SEm (±)	0.70	0.35
CD (0.05)	NS	NS
Number of harvests (H)		
h_1 (four)	16.22	3.41
h_2 (five)	17.67	4.28
h_3 (six)	18.61	5.02
SEm (±)	0.86	0.43
CD (0.05)	NS	1.248

Table 5b. Interaction effects of spacing, nutrient management and number of harvests on root depth and volume

Interactions	Root depth (cm)	Root volume (mL)
S x N interaction		
s_1n_1	16.87	4.03
s_1n_2	18.03	4.37
s_2n_1	18.17	3.96
s_2n_2	16.90	4.59
SEm (±)	0.996	0.49
CD (0.05)	NS	NS
S x H interaction		
s_1h_1	15.73	3.49
s_1h_2	16.72	4.83
s_1h_3	19.95	4.27
s_2h_1	16.72	3.33
s_2h_2	18.62	3.72
s_2h_3	17.26	5.78
SEm (±)	1.22	0.60
CD (0.05)	NS	NS
N x H interaction		
n_1h_1	16.52	3.28
n_1h_2	17.77	3.94
n_1h_3	18.27	4.77
n_2h_1	15.93	3.55
n_2h_2	17.57	4.61
n_2h_3	18.94	5.28
SEm (±)	1.22	0.60
CD (0.05)	NS	NS

Table 5c. Effect of S x N x H interaction on root depth and volume

Treatment combinations	Root depth (cm)	Root volume (mL)
$s_1n_1h_1$	15.47	3.44
$s_1n_1h_2$	14.15	4.44
$s_1n_1h_3$	21.00	4.22
$s_1n_2h_1$	15.99	3.55
$s_1n_2h_2$	19.29	5.22
$s_1n_2h_3$	18.91	4.33
$s_2n_1h_1$	17.56	3.11
$s_2n_1h_2$	21.39	3.44
$s_2n_1h_3$	15.55	5.33
$s_2n_2h_1$	15.87	3.56
$s_2n_2h_2$	15.84	4.00
$s_2n_2h_3$	18.97	6.22
SEm (±)	1.73	0.85
CD (0.05)	5.060	NS

Table 6a. Effect of spacing, nutrient management and number of harvests on leaf yield

Treatments	Number of leaves harvested per plant	Leaf yield per plant (g)	Leaf yield per 10 m^2 (kg)
Spacing (S)			
s_1 (20 cm x10 cm)	28.6	96.93	13.00
s_2 (30 cm x10 cm)	31.2	103.07	12.00
SEm (±)	0.5	1.23	0.16
CD (0.05)	1.58	3.612	0.460
Nutrient management (N)			
n_1 (inorganic)	31.0	102.41	12.97
n_2 (organic)	28.8	97.58	12.02
SEm (±)	0.5	1.23	0.16
CD (0.05)	1.58	3.612	0.460
Number of harvests (H)			
h_1 (four)	26.7	93.99	10.41
h_2 (five)	29.5	98.79	12.34
h_3 (six)	33.5	107.22	14.73
SEm (±)	0.7	1.51	0.19
CD (0.05)	1.93	4.424	0.564

Table 6b. Interaction effects of spacing, nutrient management and number of harvests on leaf yield

Interactions	Number of leaves harvested per plant	Leaf yield per plant (g)	Leaf yield per 10m^2 (kg)
S x N interaction			
s_1n_1	29.5	100.39	14.07
s_1n_2	27.6	93.47	11.92
s_2n_1	32.4	104.44	11.87
s_2n_2	30.1	101.69	12.12
SEm (±)	0.8	1.741	0.22
CD (0.05)	NS	NS	0.651
S x H interaction			
s_1h_1	26.0	91.96	11.06
s_1h_2	28.9	95.95	11.82
s_1h_3	30.7	102.89	16.10
s_2h_1	27.3	96.02	9.77
s_2h_2	30.0	102.63	12.86
s_2h_3	36.3	111.56	13.36
SEm (±)	0.9	2.13	0.27
CD (0.05)	2.73	NS	0.797
N x H interaction			
n_1h_1	27.6	94.64	10.85
n_1h_2	30.8	102.84	13.01
n_1h_3	34.4	109.77	15.04
n_2h_1	25.8	93.33	9.98
n_2h_2	28.1	94.74	11.67
n_2h_3	32.6	104.68	14.43
SEm (±)	0.9	2.13	0.27
CD (0.05)	NS	NS	NS

Table 6c. Effect of S x N x H interaction on leaf yield

Treatment combinations	Number of leaves harvested per plant	Leaf yield per plant (g)	Leaf yield per 10 m^2 (kg)
$s_1n_1h_1$	26.7	93.89	11.67
$s_1n_1h_2$	30.4	100.48	12.78
$s_1n_1h_3$	31.5	106.80	17.76
$s_1n_2h_1$	25.4	90.02	10.45
$s_1n_2h_2$	27.5	91.42	10.87
$s_1n_2h_3$	29.9	98.98	14.45
$s_2n_1h_1$	28.6	95.39	10.03
$s_2n_1h_2$	31.3	105.20	13.25
$s_2n_1h_3$	37.3	112.73	12.33
$s_2n_2h_1$	26.1	96.64	9.50
$s_2n_2h_2$	28.7	98.05	12.47
$s_2n_2h_3$	35.3	110.39	14.40
SEm (±)	1.3	3.016	0.38
CD (0.05)	NS	NS	1.127

Among interactions, the variation in number of leaves harvested was significant for S x H interaction. The combination of wider spacing and six harvests resulted in the significantly highest mean of 36.3.

Second order interaction did not record any significant influence on the number of leaves harvested per plant, but maximum number (37.3) was in $s_2n_1h_3$.

4.2.2 Leaf Yield per Plant

The per plant leaf yield varied significantly with spacing, nutrient management and number of harvests (Table 6a).

Significantly superior yields were recorded with wider spacing (103.07 g), inorganic nutrient sources (102.41 g) and six harvests (107.22 g). The first and second order interactions did not show any significant variation in the yield per plant.

4.2.3 Leaf Yield per 10 m^2

The main and interaction effects of spacing, nutrient management, and number of harvests on leaf yield per 10 m^2 area furnished in Tables 6a, 6b and 6c revealed the significant influence of the factors. Closer spacing of 20 cm x 10 cm recorded a higher yield of 13.00 kg, which was 8.33 per cent greater than the wider spacing of 30 cm x 10 cm.

Inorganic nutrition (n_1) recorded significantly higher yields (12.97 kg) and the highest number of harvests (h_3) produced the superior yield (14.73 kg). Leaf yield declined in the order of the number of harvests, $h_3 > h_2 > h_1$.

Among the first order interactions, S x N and S x H exerted significant influence on leaf yield per 10 m^2. Closer spacing in combination with inorganic nutrition (s_1n_1) recorded the significantly highest yield (14.07 kg) followed by s_2n_2 (12.12 kg). The S x H interaction, s_1h_3 (20 cm x 10 cm + six harvests) recorded the significantly highest yield of 16.10 kg from 10 m^2 area.

The second order interaction also registered significant variation in yield per 10 m^2. The combination of 20 cm x 10 cm spacing, inorganic nutrient management and six harvests ($s_1n_1h_3$) was found to be significantly superior with a yield of 17.76 kg per 10 m^2. The treatment combination, $s_2n_2h_1$ recorded the lowest yield (9.5 kg), at par with $s_1n_2h_1$ (10.45 kg) and $s_2n_1h_1$ (10.03 kg).

4.2.4 Dry Matter Production per Plant

Tables 7a, 7b and 7c present the effects of spacing, nutrient management, number of harvests and their interaction on DMP per plant in spinach beet.

The data revealed that the main effects of all the factors were significant, however, the first and second order interactions had no significant effect on DMP per plant. Wider spacing (s_2) resulted in maximum DMP (34.54 g) which was significantly superior to s_1 (32.32 g).

Inorganic nutrient management (n_1) produced significantly superior DMP (34.36 g) compared to the plants given organic nutrient sources (n_2).

The highest number of harvests taken (six) recorded the highest DMP (35.76 g) followed by five harvests (32.7 g) at par with four harvests (31.85 g).

4.3 PLANT ANALYSIS

Plant samples were collected at third and final harvests. Fresh sample analysis was done for chlorophyll and vitamin estimations, whereas dried samples were used for the estimation of NPK content.

4.3.1 NPK Uptake

The data on the effects of spacing, nutrient management and number of harvests on NPK uptake of spinach beet at final harvest are documented in Tables 7a, 7b and 7c.

4.3.1.1 N Uptake

The N uptake per plant was significantly influenced by all the three main factors. The significantly highest N uptake of 1.48 g was recorded in wider spaced plants (s_2). Among nutrient sources, maximum N uptake (1.45 g) was computed in plants manured with inorganic nutrient sources (n_1). The more the number of harvests, more was the N uptake recorded. The highest value (1.42 g) was noted in h_3 and the lowest (1.31 g) in h_1, the latter was on par with h_2 (1.33 g).

Interactions registered between S x N and N x H showed significant variations in the per plant N uptake. The combination of 30 cm x 10 cm spacing and inorganic nutrient sources (s_2n_1) recorded the highest mean of 1.51 g on par with s_2n_2 (1.45 g). The significantly lowest uptake was observed in s_1n_2 (1.06 g). Inorganic nutrition coupled with six harvests (n_1h_3) was significantly superior with respect to N uptake (1.57 g) followed by n_1h_2 (1.43 g), the latter was on par with n_1h_1 (1.35 g) but superior to n_2h_3 (1.28 g), n_2h_1 (1.26 g) and n_2h_2 (1.23 g).

The effects of S x H and S x N x H interactions were not significant.

4.3.1.2 P Uptake

Perusal of data on the effect of the treatments on P uptake per plant revealed that the main effects of spacing, nutrient management and number of harvest were significant.

Phosphorus uptake was significantly the highest (0.101 g) for plants under wider spacing (s_2) compared to those in closer spacing, s_1 (0.093 g). Inorganically manured plants (n_1) recorded significantly superior P uptake (0.105 g) compared to plants with organic nutrient management (0.089 g). In the case of number of harvests, P uptake was the highest for h_3 (six harvests) (0.102 g) and superior to h_2 and h_1 each recording 0.095 g.

Among the interactions, only S x N x H, the second order interaction, manifested significant variation on P uptake. The treatment combination $s_2n_1h_2$ recorded a higher mean of 0.119 g plant^{-1}, which was on par with $s_2n_1h_3$ (0.116 g) and $s_1n_1h_3$ (0.106 g), but superior to all other combinations.

Table 7a. Effect of spacing, nutrient management and number of harvests on DMP and NPK uptake, g per plant

Treatments	DMP	Nutrient uptake		
		N	P	K
Spacing (S)				
s_1 (20 cm x10 cm)	32.32	1.22	0.093	1.32
s_2 (30 cm x10 cm)	34.54	1.48	0.101	1.31
SEm (±)	0.44	0.02	0.002	0.02
CD (0.05)	1.283	0.059	0.005	NS
Nutrient management (N)				
n_1 (inorganic)	34.36	1.45	0.105	1.40
n_2 (organic)	32.51	1.25	0.089	1.23
SEm (±)	0.44	0.02	0.002	0.02
CD (0.05)	1.283	0.059	0.005	0.053
Number of harvests (H)				
h_1 (four)	31.85	1.31	0.095	1.22
h_2 (five)	32.70	1.33	0.095	1.35
h_3 (six)	35.76	1.42	0.102	1.37
SEm (±)	0.54	0.02	0.002	0.02
CD (0.05)	1.572	0.072	0.007	0.064

DMP – Dry matter production

Table 7b. Interaction effects of spacing, nutrient management and number of harvests on DMP and NPK uptake, g per plant

Interactions	DMP	Nutrient uptake		
		N	P	K
S x N interaction				
s_1n_1	33.44	1.39	0.100	1.40
s_1n_2	31.20	1.06	0.087	1.24
s_2n_1	35.27	1.51	0.110	1.40
s_2n_2	33.82	1.45	0.092	1.22
SEm (±)	0.62	0.03	0.003	0.03
CD (0.05)	NS	0.072	NS	NS
S x H interaction				
s_1h_1	30.87	1.19	0.094	1.20
s_1h_2	31.69	1.19	0.089	1.31
s_1h_3	34.40	1.28	0.096	1.45
s_2h_1	32.82	1.42	0.095	1.25
s_2h_2	33.70	1.47	0.100	1.38
s_2h_3	37.12	1.56	0.108	1.30
SEm (±)	0.76	0.04	0.003	0.03
CD (0.05)	NS	NS	NS	0.091
N x H interaction				
n_1h_1	32.05	1.35	0.099	1.38
n_1h_2	33.83	1.43	0.105	1.35
n_1h_3	37.18	1.57	0.111	1.47
n_2h_1	31.64	1.26	0.091	1.07
n_2h_2	31.56	1.23	0.084	1.34
n_2h_3	34.33	1.28	0.094	1.28
SEm (±)	0.76	0.04	0.003	0.03
CD (0.05)	NS	0.101	NS	0.091

DMP – Dry matter production

Table 7c. Effect of S x N x H interaction on DMP and NPK uptake, g per plant

Treatment combinations	DMP	Nutrient uptake		
		N	P	K
$s_1n_1h_1$	31.74	1.32	0.102	1.37
$s_1n_1h_2$	33.01	1.33	0.092	1.35
$s_1n_1h_3$	35.58	1.51	0.106	1.49
$s_1n_2h_1$	29.99	1.06	0.087	1.04
$s_1n_2h_2$	30.38	1.05	0.087	1.27
$s_1n_2h_3$	33.23	1.06	0.087	1.41
$s_2n_1h_1$	32.36	1.38	0.096	1.38
$s_2n_1h_2$	34.66	1.52	0.119	1.35
$s_2n_1h_3$	38.79	1.63	0.116	1.46
$s_2n_2h_1$	33.28	1.45	0.094	1.11
$s_2n_2h_2$	32.74	1.41	0.081	1.42
$s_2n_2h_3$	34.44	1.50	0.100	1.14
SEm (±)	1.071	0.05	0.005	0.04
CD (0.05)	NS	NS	0.013	0.129

DMP – Dry matter production

4.3.1.3 K Uptake

The results revealed the significant influence of nutrient management on the per plant K uptake in spinach beet. The significantly highest uptake was recorded for plants with inorganic nutrient management (1.40 g) followed by organic nutrient management (1.23 g). The main effect of number of harvests registered significant variation in K uptake with h_3 registering the highest uptake of 1.37 g on par with h_2 (1.35 g) and superior to h_1 (1.22 g).

Among first order interactions, effects of S x H and N x H were significant. In the case of S x H interaction, s_1h_3 registered the highest K uptake (1.45 g), on par with s_2h_2 (1.38 g). Inorganic nutrient management in combination with six harvests (n_1h_3) resulted in the highest K uptake (1.47 g), on par with n_1h_1 (1.38 g).

The effect of second order interaction was significant, the treatment combination $s_1n_1h_3$ registered the highest uptake of 1.49 g, on par with $s_2n_1h_1$, $s_2n_1h_3$, $s_2n_2h_2$, $s_1n_1h_1$, and $s_1n_2h_3$ but superior to all other combinations.

4.3.2 Protein Content

The mean data on the effect of the different treatments on protein content of leaves at third and final harvests are summarised in Tables 8a, 8b and 8c. The protein content was, in general higher in the leaves of the third harvest compared to that in the final harvest.

The individual effects of the factors were significant. Plants grown with wider spacing s_2 (28.63 %), inorganic nutrient sources n_1 (28.43 %) and four harvests h_1 (29.19 %) independently registered significantly higher leaf protein content.

The trend remained same at the final harvest, but significant variations were recorded only for the individual effects of spacing and nutrient management.

Table 8a. Effect of spacing, nutrient management and number of harvests on protein and chlorophyll content in leaves.

Treatments	Protein (%)		Chlorophyll (mg g^{-1})	
	Third Harvest	Final harvest	Third harvest	Final harvest
Spacing (S)				
s_1 (20 cm x10 cm)	27.73	23.58	1.37	0.78
s_2 (30 cm x10 cm)	28.63	26.87	1.47	0.74
SEm (±)	0.11	0.27	0.07	0.03
CD (0.05)	0.312	0.794	NS	NS
Nutrient management (N)				
n_1 (inorganic)	28.43	26.39	1.51	0.77
n_2 (organic)	27.92	24.06	1.32	0.76
SEm (±)	0.11	0.27	0.07	0.033
CD (0.05)	0.312	0.794	0.193	NS
Number of harvests (H)				
h_1(four)	29.19	25.54	1.47	1.16
h_2 (five)	27.60	25.36	1.38	0.70
h_3 (six)	27.74	24.79	1.40	0.43
SEm (±)	0.13	0.33	0.08	0.04
CD (0.05)	0.383	NS	NS	0.119

Table 8b. Interaction effects of spacing, nutrient management and number of harvests on protein and chlorophyll content in leaves.

	Protein (%)		Chlorophyll (mg g^{-1})	
Interactions	Third harvest	Final harvest	Third harvest	Final Harvest
S x N interaction				
s_1n_1	27.29	25.93	1.48	0.73
s_1n_2	28.15	21.25	1.26	0.84
s_2n_1	29.57	26.85	1.54	0.81
s_2n_2	27.69	26.88	1.37	0.68
SEm (±)	0.15	0.38	0.09	0.05
CD (0.05)	0.442	1.123	NS	0.137
S x H interaction				
s_1h_1	28.72	24.09	1.50	1.26
s_1h_2	27.88	23.46	1.33	0.67
s_1h_3	26.58	23.22	1.28	0.43
s_2h_1	29.67	26.99	1.44	1.06
s_2h_2	27.32	27.26	1.43	0.73
s_2h_3	28.90	26.36	1.52	0.44
SEm (±)	0.18	0.47	0.11	0.06
CD (0.05)	0.541	NS	NS	NS
N x H interaction				
n_1h_1	29.38	26.40	1.44	1.11
n_1h_2	27.56	26.42	1.64	0.77
n_1h_3	28.36	26.37	1.45	0.43
n_2h_1	29.01	24.68	1.50	1.21
n_2h_2	27.63	24.30	1.11	0.64
n_2h_3	27.12	23.21	1.34	0.43
SEm (±)	0.18	0.47	0.11	0.06
CD (0.05)	0.541	NS	0.334	NS

Table 8c. Effect of S x N x H interaction on protein and chlorophyll content in leaves

Treatment combinations	Protein (%)		Chlorophyll (mg g^{-1})	
	Third Harvest	Final harvest	Third harvest	Final harvest
$s_1n_1h_1$	27.78	26.03	1.43	1.11
$s_1n_1h_2$	26.65	25.28	1.62	0.70
$s_1n_1h_3$	27.45	26.47	1.39	0.38
$s_1n_2h_1$	29.65	22.14	1.57	1.41
$s_1n_2h_2$	29.09	21.63	1.05	0.64
$s_1n_2h_3$	25.72	19.97	1.17	0.47
$s_2n_1h_1$	30.98	26.77	1.44	1.11
$s_2n_1h_2$	28.47	27.54	1.67	0.83
$s_2n_1h_3$	29.26	26.26	1.52	0.48
$s_2n_2h_1$	28.37	27.21	1.43	1.01
$s_2n_2h_2$	26.17	26.97	1.18	0.63
$s_2n_2h_3$	28.53	26.46	1.51	0.39
SEm (±)	0.26	0.66	0.16	0.08
CD (0.05)	0.765	NS	NS	NS

The first order interactions S x N, S x H and N x H significantly influenced the protein content. Wider spacing in combination with inorganic nutrient management (s_2n_1) resulted in significantly higher protein content (29.57 %) in the third harvest, and it was the lowest (27.29 %) in the combination s_1n_1, while at final harvest, s_2n_2 was on par with s_2n_1 and s_1n_1.

Among S x H interactions, the protein content (29.67 %) was the highest in the treatment combination s_2h_1 and the lowest (26.58 %) in s_1h_3 in the third harvest leaves. Similarly N x H interaction was significant for the third harvest alone. Inorganic nutrient sources and four harvests (n_1h_1) resulted in the highest protein content (29.38 %) among N x H interactions, but was on par with n_2h_1 (29.01 %), and significantly superior to all other combinations.

S x N x H interaction remained significant in the third harvest with the highest mean for $s_2n_1h_1$ (30. 98 %) and the lowest in $s_1n_2h_3$ (25.72 %).

4.3.3 Chlorophyll Content

Variations in the chlorophyll content of spinach beet leaves as influenced by spacing, nutrient management and number of harvests at third and final harvests are depicted in Tables 8a, 8b and 8c.

At both stages, the leaves did not record any significant variation in chlorophyll content with the spacings tried. However, in the third harvest, nutrient management significantly influenced leaf chlorophyll content. Leaves of chemically fertilized plants (n_1) contained significantly higher total chlorophyll (1.51 and 0.77 mg g^{-1} at third and final harvests, respectively) than organically grown plants (n_2), the former being superior.

At the final harvest, leaf chlorophyll content showed significant variation with different number of harvests. The content was maximum (1.16 mg g^{-1}) for plants with four harvests and it decreased with increase in the number of harvests.

Among first order interactions, S x N showed significant effect on leaf chlorophyll content at final harvest and s_1n_2 recorded a higher value of 0.84 mg g^{-1} at par with s_2n_1 (0.81 mg g^{-1}) and s_1n_1 (0.73 mg g^{-1}), but significantly superior to s_2n_2 (0.68 mg g^{-1}). S x H interaction effects were not significant. In N x H interaction, in the third harvest plants manured with inorganic nutrient sources in combination with five harvests (n_1h_2) recorded a higher content (1.64 mg g^{-1}), on par with n_2h_1, n_1h_3, n_1h_1 and n_2h_3.

The second order interaction did not exert any significant variation in the chlorophyll content in the leaves at third and final harvest stages.

4.3.4 Vitamin A

The results on the effects of spacing, nutrient management and number of harvests on vitamin A in terms of total carotene content, at third and final harvests are shown in Tables 9a, 9b and 9c. The contents were found to be comparatively higher in the leaves of the third harvest compared to that in the later stages of harvest.

There was no variation in the leaf vitamin A content with the spacings tried, at both stages of estimation, while it was significantly influenced by nutrient management practices. Organically grown plants (n_2) registered higher carotene content of 7.18 and 3.20 mg 100 g^{-1}, at third and final harvest respectively.

The effect of number of harvests was found to be significant at both stages, maximum carotene content was observed in the plants harvested four times (6.90 and 3.60 mg 100g^{-1}, respectively).

The first order interaction, S x N registered significant effect on total carotene content at third harvest, closer spacing in combination with organic nutrient sources (s_1n_2) recorded the higher mean of 7. 54 mg 100 g^{-1}, at par with s_2n_2, wider spacing of 30 cm x 10 cm and organic nutrition (6.83 mg 100 g^{-1}), but significantly superior to s_2n_1 (6.27 mg 100 g^{-1}) and s_1n_1(4.38 mg 100 g^{-1}).

The effect of S x H, N x H and S x N x H were non significant at both, third and final harvests.

Table 9a. Effect of spacing, nutrient management and number of harvests on vitamin A and C content of leaves, mg 100 g^{-1}

Treatments	Vitamin A		Vitamin C	
	Third harvest	Final harvest	Third harvest	Final harvest
Spacing (S)				
s_1 (20 cm x10 cm)	5.96	2.86	39.56	29.01
s_2 (30 cm x10 cm)	6.55	2.85	37.01	28.74
SEm (±)	0.23	0.20	1.72	1.09
CD (0.05)	NS	NS	NS	NS
Nutrient management (N)				
n_1 (inorganic)	5.33	2.52	35.12	26.07
n_2 (organic)	7.18	3.20	41.56	31.68
SEm (±)	0.23	0.20	1.72	1.09
CD (0.05)	0.667	0.594	5.054	3.203
Number of harvests (H)				
h_1 (four)	6.90	3.60	39.58	31.57
h_2 (five)	6.21	2.82	38.14	28.57
h_3 (six)	5.66	2.15	37.13	26.49
SEm (±)	0.28	0.25	2.11	1.34
CD (0.05)	0.817	0.728	NS	3.922

Table 9b. Interaction effects of spacing, nutrient management and number of harvests on vitamin A and C content of leaves, mg 100 g^{-1}

Interactions	Vitamin A		Vitamin C	
	Third Harvest	Final harvest	Third harvest	Final harvest
S x N interaction				
s_1n_1	4.38	2.62	35.67	26.32
s_1n_2	7.54	3.11	43.45	31.70
s_2n_1	6.27	2.42	34.56	25.81
s_2n_2	6.83	3.29	39.46	31.67
SEm (±)	0.32	0.29	2.44	1.54
CD (0.05)	0.943	NS	NS	NS
S x H interaction				
s_1h_1	6.42	3.58	39.04	30.38
s_1h_2	5.86	3.01	42.22	30.46
s_1h_3	5.61	2.00	37.42	26.19
s_2h_1	7.38	3.63	40.12	32.76
s_2h_2	6.55	2.63	34.07	26.67
s_2h_3	5.72	2.30	36.85	26.80
SEm (±)	0.39	0.35	2.98	1.89
CD (0.05)	NS	NS	NS	NS
N x H interaction				
n_1h_1	5.87	2.90	34.60	27.92
n_1h_2	5.11	2.50	35.55	25.54
n_1h_3	5.00	2.15	35.19	24.74
n_2h_1	7.93	4.30	44.56	35.22
n_2h_2	7.30	3.15	40.74	31.59
n_2h_3	6.33	2.16	39.07	28.25
SEm (±)	0.39	0.35	2.98	1.89
CD (0.05)	NS	NS	NS	NS

Table 9c. Effect of S x N x H interaction on vitamin A and C content of leaves, mg 100 g^{-1}

Treatment combinations	Vitamin A		Vitamin C	
	Third Harvest	Final harvest	Third harvest	Final harvest
$s_1n_1h_1$	5.00	3.20	35.13	27.37
$s_1n_1h_2$	3.98	2.67	40.00	27.38
$s_1n_1h_3$	4.28	2.00	31.87	24.22
$s_1n_2h_1$	7.94	3.95	42.96	33.39
$s_1n_2h_2$	7.75	3.36	44.44	33.54
$s_1n_2h_3$	6.94	2.03	42.96	28.15
$s_2n_1h_1$	6.85	2.61	34.07	28.48
$s_2n_1h_2$	6.25	2.33	31.11	23.70
$s_2n_1h_3$	5.72	2.32	38.52	25.26
$s_2n_2h_1$	7.92	4.66	46.17	37.04
$s_2n_2h_2$	6.85	2.93	37.03	29.63
$s_2n_2h_3$	5.71	2.29	35.18	28.34
SEm (±)	0.56	0.50	4.22	2.67
CD (0.05)	NS	NS	NS	NS

4.3.5 Vitamin C

Tables 9a, 9b and 9c illustrate the variations in vitamin C content in the leaves at third and final harvests. The ascorbic acid content was higher for third harvest leaves compared to those in the final harvest.

Among the individual effects, there was significant difference in the vitamin C content in the leaves of the third and final harvest in spinach beet with nutrient management and number of harvests.

Comparing the vitamin C content in the third harvest, plants manured with organic nutrient sources (n_2) recorded significantly superior vitamin C content than that in plants given inorganic nutrient sources (n_1), the value in n_2 being 41.56 mg 100 g^{-1} . None of interactions registered significant variations in vitamin C content.

Comparing the vitamin C content of the last harvested leaves, it was observed that although spacing did not indicate any significant influence, nutrient management and number of harvest could bring about significant differences.

The significantly highest ascorbic acid content (31.68 mg 100 g^{-1}) was observed with organically grown plants (n_2), while the inorganically raised crop recorded vitamin C content of 26.07 mg 100 g^{-1}.

With respect to the number of harvests, vitamin C content decreased with increase in the number of harvests and the higher mean (31.57 mg 100 g^{-1}) was obtained for plants with four harvests (h_1), on par with h_2 (28.57 mg 100 g^{-1}). The first and second order interaction effects were found to be non significant.

4.4 SOIL ANALYSIS

The results on the effect of spacing, nutrient management, number of harvests and their interaction on soil chemical properties are as follows.

4.4.1 Soil pH

Perusal of the data (Tables 10a, 10b and 10 c) showed that all the main and interaction effects on soil pH were non significant, nevertheless, it increased from the initial value (5.89) towards the neutral range with the treatments in spinach beet cultivation.

Table 10a. Effect of spacing, nutrient management and number of harvests on pH and organic C content of soil

Treatments	pH	Organic C (%)
Spacing (S)		
s_1 (20 cm x10 cm)	6.52	1.19
s_2 (30 cm x10 cm)	6.65	1.20
SEm (±)	0.12	0.01
CD (0.05)	NS	NS
Nutrient management (N)		
n_1 (inorganic)	6.72	1.17
n_2 (organic)	6.45	1.22
SEm (±)	0.12	0.01
CD (0.05)	NS	0.038
Number of harvests (H)		
h_1 (four)	6.75	1.24
h_2 (five)	6.52	1.18
h_3 (six)	6.49	1.17
SEm (±)	0.13	0.02
CD (0.05)	NS	0.047

Table 10b. Interaction effect of spacing, nutrient management and number of harvests on pH and organic C content of soil

Interactions	pH	Organic C (%)
S x N interaction		
s_1n_1	6.62	1.14
s_1n_2	6.43	1.23
s_2n_1	6.82	1.18
s_2n_2	6.48	1.22
SEm (±)	0.15	0.02
CD (0.05)	NS	NS
S x H interaction		
s_1h_1	6.67	1.21
s_1h_2	6.62	1.18
s_1h_3	6.29	1.17
s_2h_1	6.85	1.27
s_2h_2	6.42	1.17
s_2h_3	6.69	1.16
SEm (±)	0.18	0.02
CD (0.05)	NS	NS
N x H interaction		
n_1h_1	6.83	1.22
n_1h_2	6.74	1.14
n_1h_3	6.70	1.13
n_2h_1	6.68	1.26
n_2h_2	6.30	1.21
n_2h_3	6.38	1.20
SEm (±)	0.18	0.02
CD (0.05)	NS	NS

Table 10c. Effect of S x N x H interaction on pH and organic C content of soil

Treatment combinations	pH	Organic C (%)
$s_1n_1h_1$	6.66	1.17
$s_1n_1h_2$	6.72	1.16
$s_1n_1h_3$	6.48	1.12
$s_1n_2h_1$	6.67	1.25
$s_1n_2h_2$	6.51	1.20
$s_1n_2h_3$	6.10	1.23
$s_2n_1h_1$	6.99	1.27
$s_2n_1h_2$	6.76	1.12
$s_2n_1h_3$	6.72	1.15
$s_2n_2h_1$	6.70	1.26
$s_2n_2h_2$	6.08	1.22
$s_2n_2h_3$	6.66	1.17
SEm (±)	0.26	0.03
CD (0.05)	NS	NS

4.4.2 Organic Carbon

The main and interaction effects of spacing, nutrient management and number of harvests on organic C content in soil are depicted in Tables 10 a, 10 b and 10 c

The results showed that spacing had no significant effect on organic C content. On the other hand, nutrient management and number of harvests showed significant variations. Organically fertilized plots had significantly superior organic C content (1.22 %) than chemical fertilizer applied plots (1.17 %).

Among number of harvests, h_1 recorded the highest organic C content of (1.24 %) followed by h_2 (1.18 %) and h_3 (1.17 %).

4.4.3 Available NPK

The changes in soil available nutrient status are furnished in Tables 11a, 11b and 11c.

4.4.3.1 Available N

The results revealed that main effect of nutrient management alone had significant effect on available N status in soil after the experiment. Organic nutrient sources resulted in significantly maximum mean value (226.4 kg ha^{-1}) compared to inorganic nutrient management (218.72 kg ha^{-1}).

The interactions, both first and second order, did not record any significant influence on the soil available N status.

4.4.3.2 Available P

Perusal of data showed that spacing had significant effect on available P status and the content was significantly the highest for s_2 (55.02 kg ha^{-1}) compared to s_1 (52.66 kg ha^{-1}).

Among the interactions, S x N showed significant variation in available P status. Wider spacing in combination with inorganic nutrient sources (s_2n_1) resulted in higher P content (56.01 kg ha^{-1}), at par with s_2n_2 (54.03 kg ha^{-1}) and s_1n_2 (53.93 kg ha^{-1}).

The interactions S x H, N x H and S x N x H had no significant effect.

Table 11a. Effect of spacing, nutrient management and number of harvests on available nutrient status in soil, (kg ha^{-1})

Treatments	Available N	Available P	Available K
Spacing (S)			
s_1 (20 cm x10 cm)	225.24	52.66	187.19
s_2 (30 cm x10 cm)	219.88	55.02	187.66
SEm (±)	1.87	0.63	0.72
CD (0.05)	NS	1.852	NS
Nutrient management (N)			
n_1 (inorganic)	218.72	53.70	184.05
n_2 (organic)	226.40	53.98	190.71
SEm (±)	1.87	0.63	0.72
CD (0.05)	5.493	NS	2.102
Number of harvests (H)			
h_1 (four)	223.83	53.40	191.06
h_2 (five)	224.34	54.12	186.18
h_3 (six)	219.50	54.00	185.03
SEm (±)	2.29	0.77	0.88
CD (0.05)	NS	NS	2.574

Table 11b. Interaction effect of spacing, nutrient management and number of harvests on available nutrient status in soil, kg ha^{-1}

Interactions	Available N	Available P	Available K
S x N Interaction			
s_1n_1	219.34	51.38	183.98
s_1n_2	231.14	53.93	190.40
s_2n_1	218.10	56.01	184.13
s_2n_2	221.66	54.03	191.18
SEm (±)	2.65	0.89	1.01
CD (0.05)	NS	2.619	NS
S x H interaction			
s_1h_1	228.40	51.41	191.96
s_1h_2	224.56	53.66	187.62
s_1h_3	222.75	52.90	181.99
s_2h_1	219.26	55.38	190.16
s_2h_2	224.13	54.58	184.73
s_2h_3	216.25	55.10	188.07
SEm (±)	3.24	1.09	1.24
CD (0.05)	NS	NS	3.640
N x H interaction			
n_1h_1	220.42	52.01	184.99
n_1h_2	221.05	54.08	186.12
n_1h_3	214.68	55.00	181.05
n_2h_1	227.24	54.78	197.13
n_2h_2	227.64	54.17	186.23
n_2h_3	224.31	53.00	189.01
SEm (±)	3.24	1.09	1.24
CD (0.05)	NS	NS	3.640

Table 11c. Effect of S x N x H interaction on available nutrient status in soil, kg ha^{-1}

Treatment combinations	Available N	Available P	Available K
$s_1n_1h_1$	223.97	48.91	185.35
$s_1n_1h_2$	217.55	51.96	186.07
$s_1n_1h_3$	216.50	53.27	180.51
$s_1n_2h_1$	232.84	53.90	198.56
$s_1n_2h_2$	231.57	55.37	189.17
$s_1n_2h_3$	228.99	52.53	183.47
$s_2n_1h_1$	216.88	55.10	184.62
$s_2n_1h_2$	224.55	56.20	186.17
$s_2n_1h_3$	212.87	56.73	181.59
$s_2n_2h_1$	221.63	55.67	195.70
$s_2n_2h_2$	223.70	52.97	183.30
$s_2n_2h_3$	219.63	53.47	194.54
SEm (±)	4.59	1.55	1.76
CD (0.05)	NS	NS	5.148

4.4.3.3 Available K

The main effect of the factors, nutrient management and number of harvests alone recorded significant variation in soil available K content. Available K content was significantly superior for organic nutrient management (n_2) and four harvests (h_1) independently, the values being 190.71 and 191.06 kg ha^{-1}, respectively.

Among first order interactions, S x H and N x H showed significant effect, closer spacing in combination with four harvests (s_1h_1) resulted in highest available K content of 191.96 kg ha^{-1} , at par with s_2h_1 (190.16 kg ha^{-1}).

The N x H interaction, n_2h_1 (organic nutrient sources + four harvests) recorded significantly superior K content (197.13 kg ha^{-1}) and it was lowest in n_1h_3 (181.05 kg ha^{-1}).

The effect of second order interaction was also significant, $s_1n_2h_1$ (20 cm x 10 cm + organic nutrient management + four harvests) resulted in maximum K content (198.56 kg ha^{-1}), on par with $s_2n_2h_1$ (195.70 kg ha^{-1}) and $s_2n_2h_3$ (194.54 kg ha^{-1}).

4.4.4 Microbial Count

The main and interaction effects of spacing, nutrient management and number of harvests on the count of bacteria, actinomycetes and fungi in soil after the experiment are presented in Tables 12a, 12b and 12c.

4.4.4.1 Bacteria

The variations noticed in soil bacterial population with nutrient management alone was significant. The population was the highest for n_2 (organic sources) with a count of 90.8 x 10^6 cfu g^{-1} soil, whereas inorganic nutrient management (n_1) registered a lower count of 62.7 x 10^6 cfu g^{-1} soil.

Among the interaction effects, the first order interactions S x H and N x H registered significant variations. The interaction s_2h_3 recorded the highest mean value of 100 x 10^6 cfu g^{-1} soil, which was at par with s_1h_1 (81 x 10^6 cfu g^{-1}soil) and significantly superior to the other S x H interactions.

Table 12a. Variations in soil microbial count as influenced by spacing, nutrient management and number of harvests, cfu g^{-1} soil

Treatments	Microbial count		
	Bacteria (x 10^6)	Actinomycetes (x 10^4)	Fungi (x 10^3)
Spacing (S)			
s_1 (20 cm x 10cm)	70.3	12.6	57.2
s_2 (30 cm x 10 cm)	83.2	12.6	52.3
SEm (±)	4.6	0.7	1.5
CD (0.05)	NS	NS	4.50
Nutrient management(N)			
n_1 (inorganic source)	62.7	10.7	43.0
n_2 (organic source)	90.8	14.5	66.5
SEm (±)	4.6	0.7	1.5
CD (0.05)	13.36	2.12	4.50
Number of harvests (H)			
h_1 (four)	76.3	12.6	51.9
h_2 (five)	72.8	12.8	53.8
h_3 (six)	81.2	12.5	58.5
SEm (±)	5.6	0.95	1.9
CD (0.05)	NS	NS	NS

Table 12b. Interaction effect of spacing, nutrient management and number of harvests on soil microbial count, cfu g^{-1} soil

Interactions	Microbial count		
	Bacteria (x 10^6)	Actinomycetes (x 10^4)	Fungi (x 10^3)
S x N interaction			
s_1n_1	62.6	11.0	41.9
s_1n_2	78.0	14.1	72.4
s_2n_1	62.8	10.3	44.1
s_2n_2	103.7	14.9	60.6
SEm (±)	6.4	1.0	2.2
CD (0.05)	NS	NS	6.37
S x H interaction			
s_1h_1	81.0	11.7	52.5
s_1h_2	67.5	13.7	53.8
s_1h_3	62.3	12.4	65.2
s_2h_1	71.5	13.5	51.3
s_2h_2	78.2	11.8	53.8
s_2h_3	100.0	12.5	51.8
SEm (±)	7.88	1.3	2.7
CD (0.05)	23.14	NS	7.80
N x H interaction			
n_1h_1	81.0	09.5	46.7
n_1h_2	51.7	11.6	40.2
n_1h_3	55.3	10.5	42.2
n_2h_1	71.5	13.53	57.2
n_2h_2	94.0	11.82	67.5
n_2h_3	107.0	12.5	74.8
SEm (±)	7.9	1.3	2.7
CD (0.05)	23.14	NS	7.80

Table 12c. Effect of S x N x H interaction on soil microbial count, cfu g^{-1} soil

Treatment combinations	Microbial count		
	Bacteria (x 10^6)	Actinomycetes (x 10^4)	Fungi (x 10^3)
$s_1n_1h_1$	94.3	8.6	45.3
$s_1n_1h_2$	42.7	14.2	37.0
$s_1n_1h_3$	50.7	10.3	43.3
$s_1n_2h_1$	67.7	14.7	59.7
$s_1n_2h_2$	92.3	13.2	70.7
$s_1n_2h_3$	74.0	14.5	87.0
$s_2n_1h_1$	67.7	11.3	48.0
$s_2n_1h_2$	60.7	09.3	43.3
$s_2n_1h_3$	60.0	10.7	41.0
$s_2n_2h_1$	75.3	15.7	54.7
$s_2n_2h_2$	95.7	14.6	64.3
$s_2n_2h_3$	140.0	14.3	62.7
SEm (±)	11.2	1.8	3.8
CD (0.05)	NS	NS	NS

The combination of organic nutrient management and six harvests (n_2h_3) recorded the highest count of 107.0 x 10 ^{6} cfu g^{-1} soil, at par with n_2h_2, and the lowest count of 51.7 x 10 ^{6} cfu g^{-1}soil was recorded in n_1h_2.

The interaction effects of S x N and S x N x H were not significant.

4.4.4.2 Actinomycetes

On scrutiny of the mean data, it was evident that nutrient management alone exerted significant influence on actinomycete population. It was significantly higher for organic nutrient sources (14.5 x 10^4 cfu g^{-1}soil) compared to inorganic nutrient management (10.7 x 10 ^{4} cfu g^{-1} soil).

No significant variations were observed in the actinomycete count with the first and second order interactions.

4.4.4.3 Fungi

The population of fungi in soil after the experiment showed significant variation with the factors, spacing and nutrient management. Fungal count enumerated (57.2 x 10^3 cfu g^{-1} soil) was significantly higher in s_1, (20 cm x 10 cm). Of the nutrient management practice adopted, organic nutrition (n_2) recorded the highest population (66.5 x 10^3 cfu g^{-1} soil).

The first order interactions S x N, S x H and N x H showed significant variations in fungal population. The combination of 20 cm x 10 cm spacing and organic nutrient management (s_1n_2) registered highest mean of 72.4 x 10^3 cfu g^{-1}soil. The counts in treatments involving inorganic nutrient sources were the lowest. Closer spacing in combination with six harvests (s_1h_3) resulted in the highest mean (65.2 x 10^3 cfu g^{-1} soil) and the count was lowest for s_2h_1 (51.3 x 10^3 cfu g^{-1} soil).

Organic nutrient management coupled with six harvests (n_2h_3) resulted in the significantly highest fungal population of 74.8 x 10^3 cfu g^{-1} soil and lowest count was obtained with inorganic nutrition and five harvests (40.2 x 10^3 cfu g^{-1} soil). The three factor interaction showed no significant variation in soil fungal population.

4. 5 MICROCLIMATE

The microclimatic parameters inside the rain shelter monitored during the cropping season are depicted in Fig. 3. Air temperature inside the rain shelter varied between the weekly mean of 30.11 and 34.32°C during the cropping period. It was 1 to 2 ° C higher than the ambient temperature. The lowest mean soil temperature of 27.3°C was recorded during the first week of the cropping period and maximum mean value of 29.4°C during the 50th standard week. The RH inside the rain shelter ranged from 77. 23 to 92.11 per cent, 7 to 8 per cent higher than the average minimum RH under open condition. Light intensity inside the rain shelter at crop canopy level varied in the range of 10.3 to 17.9 k lux during the cropping period and it was 60 to 70 k lux lower than open condition.

4.6 PEST AND DISEASE INCIDENCE

Incidence of damping off by *Rhizoctonia solani* was the major problem noticed in the field. Leaf feeders like *Spodoptera litura* and leaf webber *Hymenia recurvalis* incidence occurred at periods of peak vegetative growth due to mutual shading by plants after second harvest (60 DAS).

4.7 ECONOMIC ANALYSIS

Table 13 depicts the results of economic analysis of the effect of spacing, nutrient management and number of harvests in spinach beet.

The combination of closer spacing, inorganic nutrient management and six harvests ($s_1n_1h_3$) recorded the highest gross income (₹888), net income (₹406) and BCR (1.84) followed by the combination ($s_1n_2h_3$) of closer spacing, organic nutrition and six harvests with a BCR of 1.47.

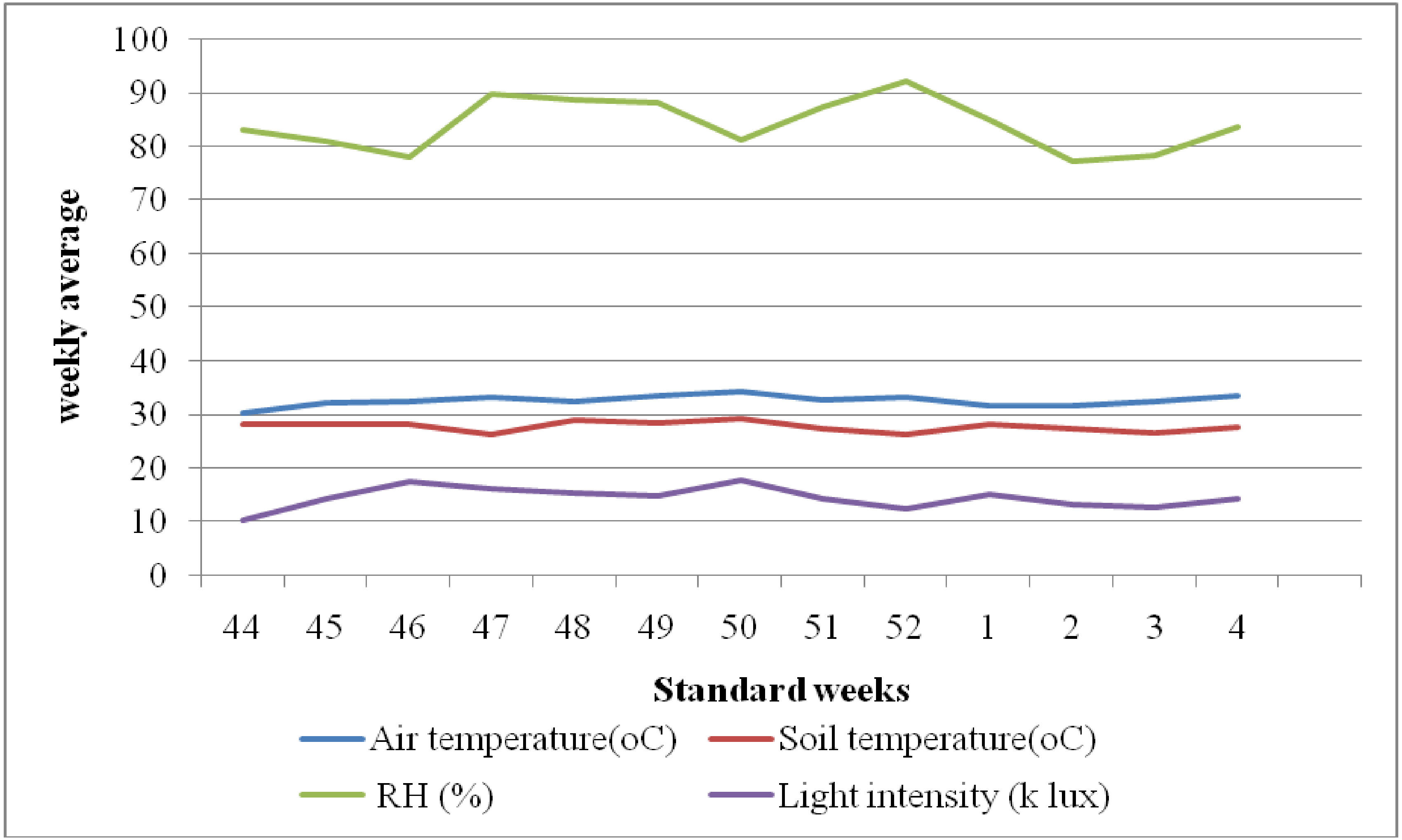

Fig. 3 Microclimatic parameters during the cropping season inside the rain shelter

Table 13. Economics of cultivation

Treatment combinations	Gross income ₹10 m^{-2}	Net income ₹10 m^{-2}	BCR
$s_1n_1h_1$	583.5	132.2	1.29
$s_1n_1h_2$	639.0	182.1	1.40
$s_1n_1h_3$	888.0	406.2	1.84
$s_1n_2h_1$	627.0	58.8	1.10
$s_1n_2h_2$	652.2	81.9	1.14
$s_1n_2h_3$	867.0	278.8	1.47
$s_2n_1h_1$	501.5	59.4	1.13
$s_2n_1h_2$	662.5	204.3	1.45
$s_2n_1h_3$	616.5	162.9	1.36
$s_2n_2h_1$	570.0	6.50	1.01
$s_2n_2h_2$	748.2	169.9	1.29
$s_2n_2h_3$	864.0	275.0	1.46

BCR- Benefit cost ratio

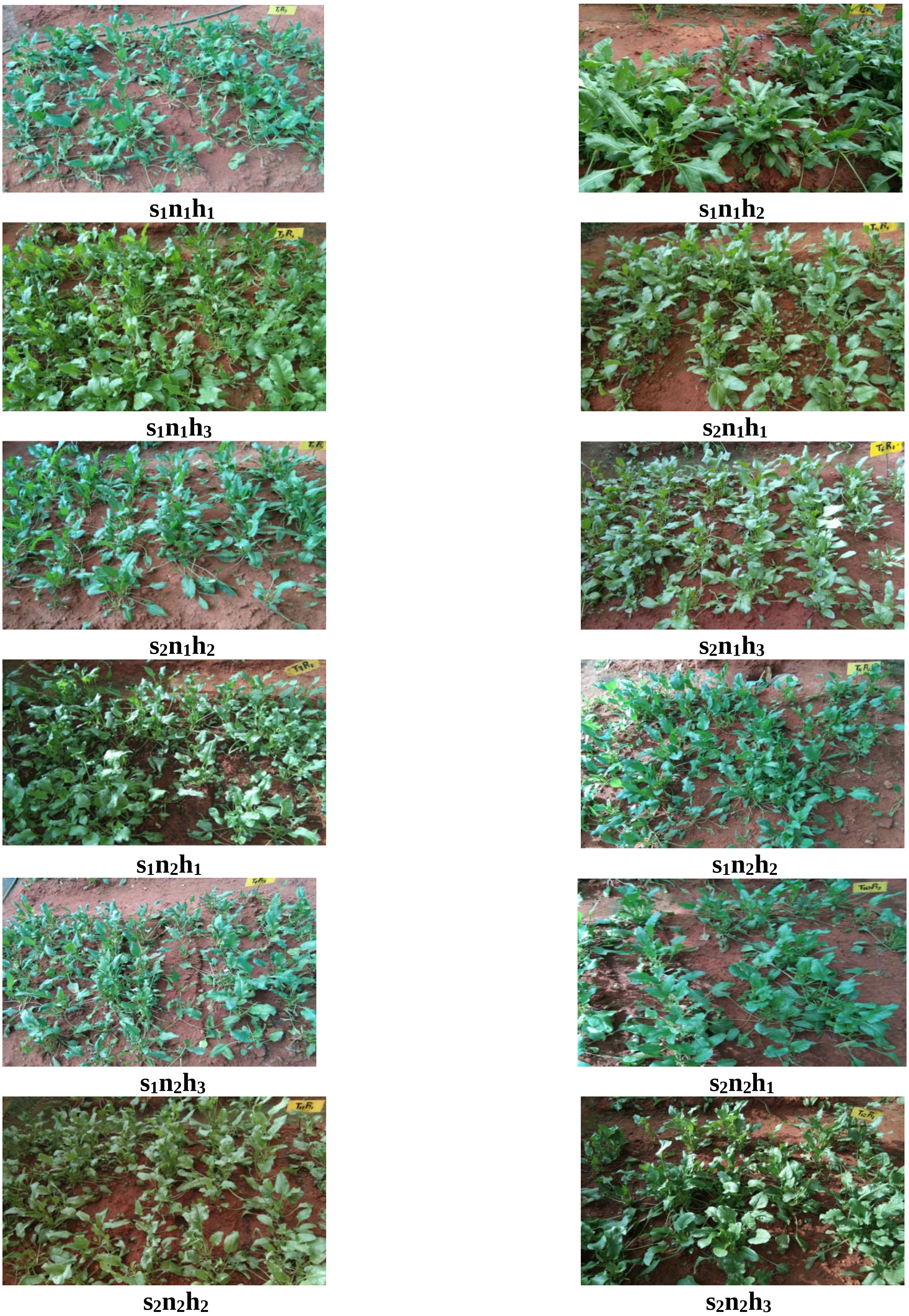

Plate. 2. Treatment wise view of plots

DISCUSSION

5. DISCUSSION

The leafy vegetable **s**pinach beet, commonly called palak, responds well to management practices and increasing the productivity calls for research results on appropriate technologies for its cultivation. In this chapter, an effort has been made to critically discuss the results of the experiment detailed in the previous chapter.

5.1 GROWTH AND YIELD

Spinach beet is a short statured annual crop with simple leaves that stem from the centre of the plant and grow in a rosette. The agronomic practices of planting geometry, nutrient management and multiple harvests included in the study significantly influenced the growth and leaf yields.

The results of the experiment revealed the significant influence of the management practices on plant height at various growth stages from 30 DAS to final harvest. In general, plant height increased with growth, and towards the final stages, 80 to 105 DAS, plants were shorter on account of re-growth that occurred after each picking, and the later formed leaves failing to attain the size of the first formed leaves.

Of the two spacings tried, closer spacing (20 cm x 10 cm) resulted in taller plants compared to those planted at 30 cm x 10 cm. It is inferred that proper management practices led to higher vegetative growth, which when spaced close, resulted in mutual shading. Lower light intensity reduces the photo oxidation of auxin that promotes cell division and enlargement in the apical meristem (Behringer and Davies, 1992). Competition for light under closer spacing also causes basal internode elongation, due to enhanced gibberillic acid biosynthesis, and these result in increased plant height so as to intercept more radiation (Beall *et al.*, 1996). Mane (2003) and later, Diwan *et al*. (2018), reported significant increase in plant height in response to mutual shading under closer spacing. In spinach beet, based on its unique plant stature, more than the stem, the petiole was found to be longer and hence the leaf length, contributing to the plant height. The results are in congruence with the reports of Yarnia (2010) and Tiwari *et al*. (2016).

Plant height was significantly influenced by nutrient sources from 30 DAS to third harvest (70 DAS). Spinach beet plants, grown with inorganic nutrient sources (urea, rajphos and MOP) were taller than organically grown plants (vermicompost, rajphos, wood ash and AMF). This would be due to the readily available forms of nutrients in chemical fertilizers. A similar result was reported by Sarker *et al*. (2002) in cabbage at 90 days after transplanting (DAT).

The significant influence of cutting management on plant height was observed only at the final harvest stage. The final harvest in h_1 was the fourth harvest (80 DAS), in h_2, the fifth harvest (95 DAS) and in h_3, the sixth harvest (105 DAS). As two additional cuttings were taken, the plant height recorded in h_3 was significantly the lowest (30.97 cm). This may be attributed to the breakdown of apical dominance with cuttings which encouraged the plants to produce more side shoots and leaves. According to Fu (2008), repeated cuttings also result in loss of photosynthates that otherwise could have been used by the plant for its growth. Evidences for decreased plant height with increased number of cuttings have been documented by Patil and Naik (2004) and Tehlan and Thakral (2008).

The combinations of closer spacing, inorganic nutrient management and/ four harvests *viz*., s_1n_1 (30 DAS), s_1n_1 (60 DAS), n_2h_3 (70 DAS) recorded significantly taller plants, which is deduced to be due to the positive interaction of individual effects as explained above.

Vegetative growth decides the yield in spinach beet. Hence the management practices that maximize leaf production can be identified as the suitable agrotechniques in the crop. Analysis of the results of the present study showed maximum leaf area and LAI at 70 DAS, and the values declined as growth progressed and with further harvests (Fig. 4a and Fig. 4b).

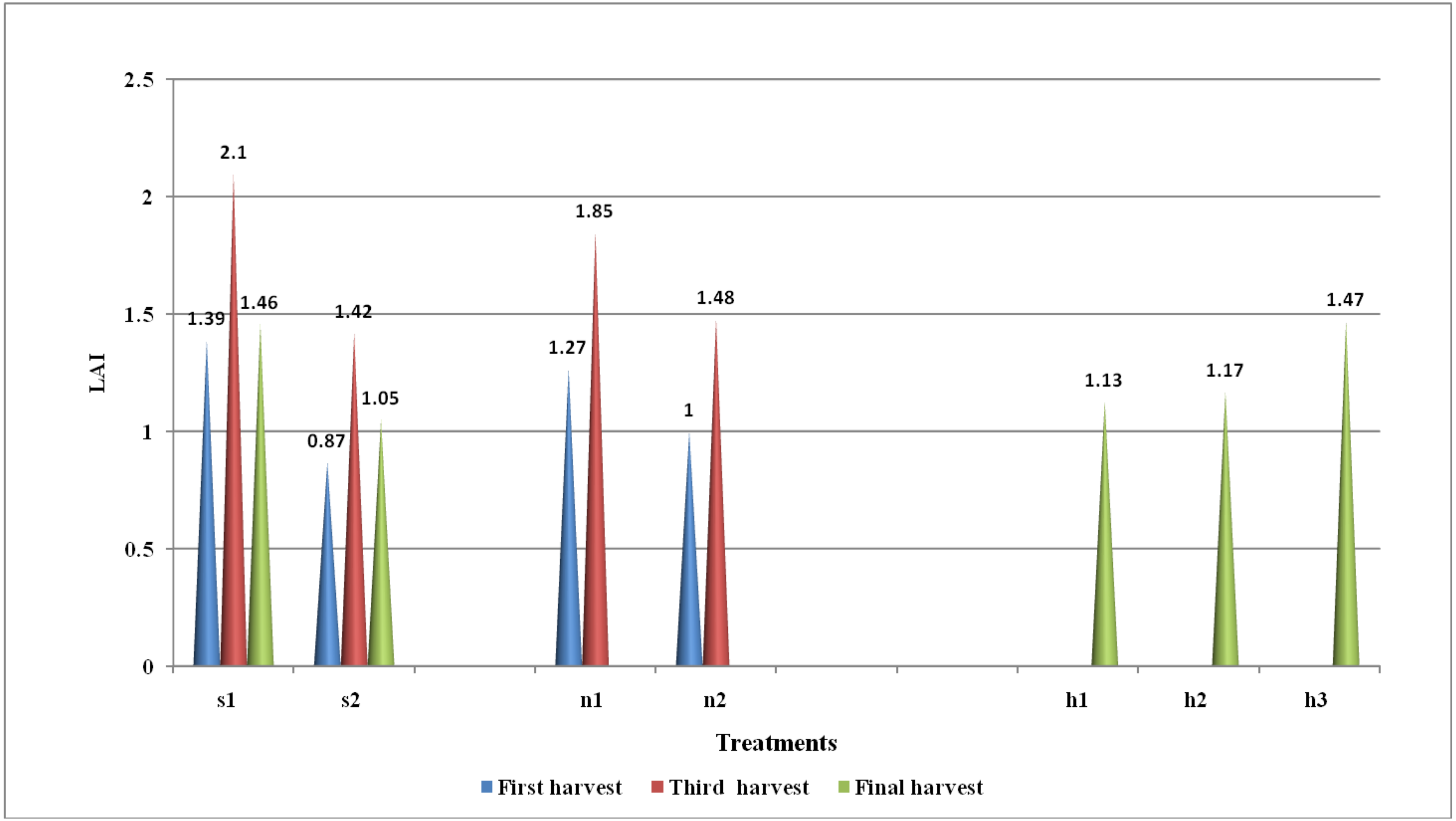

Fig. 4a Individual effects of spacing (S), nutrient management (N) and number of harvests (H) on LAI

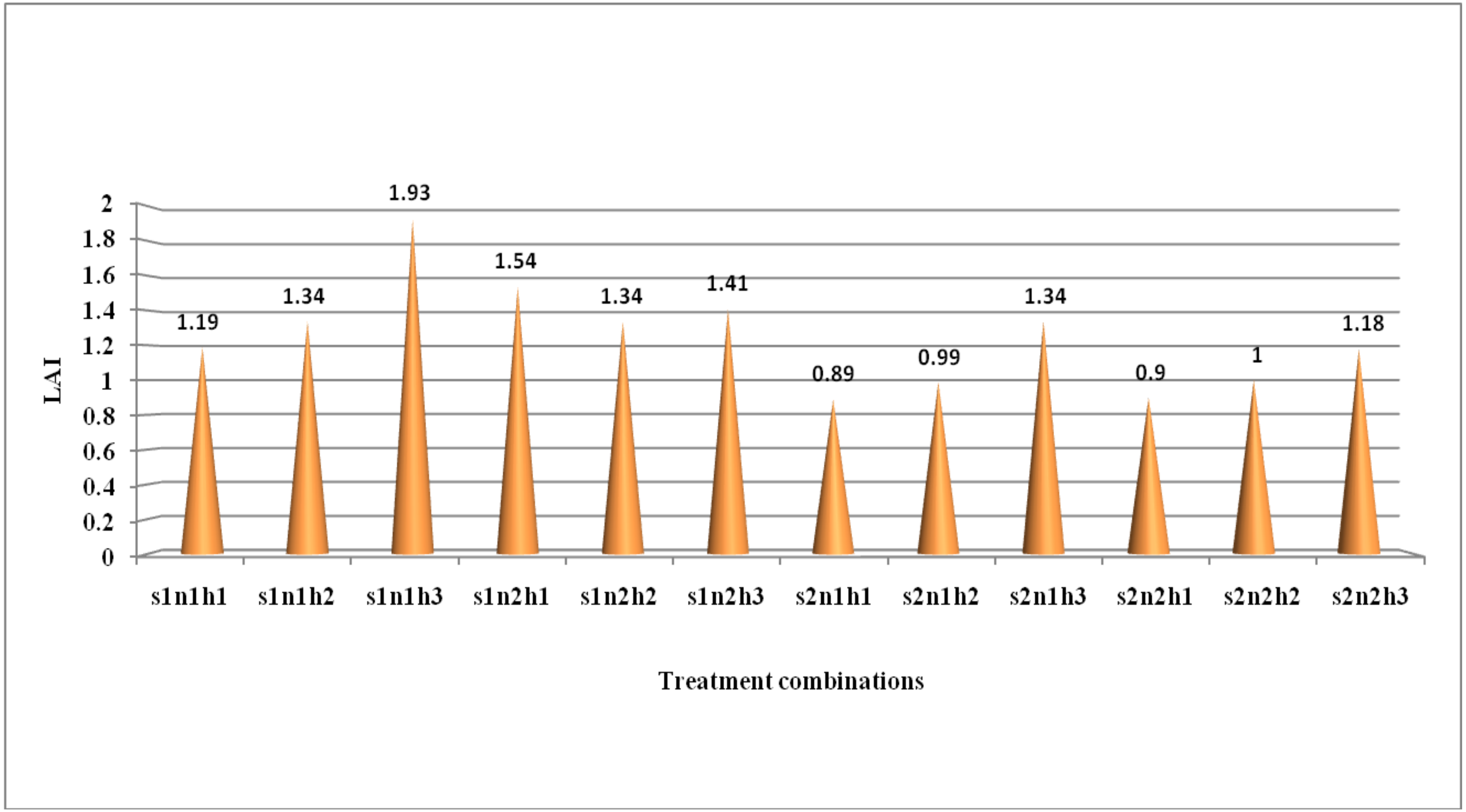

Fig. 4b Interaction effects, S x N x H on LAI

Leaf area was significantly higher for plants grown under wider spacing (s_2), with inorganic nutrient management (n_1) and six harvests (h_3) and their combinations *viz.*, s_2n_1 (60 DAS), n_1h_2 at par with n_1h_3 (70 DAS), n_1h_3 (final harvest). In the case of LAI, significantly superior values were recorded for closer spacing s_1 (1.46), n_1 (1.27 and 1.85 at 40 and 70 DAS respectively) and h_3 (1.47) and the combinations *viz.*, n_1h_2 at par with n_1h_3 at 70 DAS and n_1h_3 (1.64), $s_1n_1h_3$ (1.93) at final harvest stage.

An optimum plant population is crucial for plants to utilize the available resources and convert them into yields. In this study, plants under closer spacing recorded lower leaf area and lesser number of leaves (Fig. 5) on account of the inter plant competition for growth factors due to the higher plant density. The widely spaced plants on the contrary were benefitted and the better access and utilization of the resources stimulated the production of larger sized and more number of leaves. This resulted in the higher leaf area per plant in s_2. The results are in conformity with the findings of Biemond (2004) and Yarnia (2010) in amaranthus.

Chakraborty *et al*. (2015) based on their study, opined that the increased spacing ensured availability of ample sunlight and free aeration, which resulted in maximum vegetative growth in palak. Higher plant density alters the intensity and quality of intercepted radiation and in turn reduces the assimilation and growth in plants (Gautier *et al*., 1999). Plant density has direct influence on physiology (Oad *et al*., 2001). Lower light intensity owing to a closed canopy in a dense vegetation limits leaf area expansion to alleviate the below ground competition for growth factors and this in turn reduces growth and yield of crops in higher plant densities.

Even though the total leaf area increased with spacing, the LAI computed was lower on account of the higher plant to plant spacing. The index is calculated based on spacing and hence, despite the larger leaf area, LAI recorded was lower in widely spaced plants.

Nutrient management significantly influenced leaf production. Plants fertilized with inorganic nutrient sources were significantly superior with respect to leaf area and LAI, which can be ascribed to the enhanced availability of nutrients from readily soluble fertilizers compared to the organic sources. Organic sources are considered slow release fertilizers as mineralization has to occur for the nutrients, especially N, to become available. Spinach beet, variety All Green is of short duration and the first harvest was taken 40 DAS, and subsequently at 10-20 days interval. It is interpreted that the crop needed readily available nutrient sources for rapid uptake and utilization within the plant. Several comparative studies between organic and inorganic nutrient management authenticate that chemical fertilizers promoted leaf production and increased leaf area on account of the ease in nutrient availability. These were illustrated by Bharad *et al*. (2013) in spinach beet and Sarkar *et al*. (2014a) in water spinach.

The importance of the nutrients, N, P and K in enhancing vegetative growth has been established by several workers. Increased leaf area in spinach beet (Nawawi *et al.*, 1986) and higher leaf area, LAI and leaf area duration (LAD) in amaranthus (Malligawad, 1994) in response to N application have been reported. Wang and Li (2004) illustrated increased vegetative growth in cabbage with P fertilization and Dzida *et al*. (2011) reported positive response of leafy vegetables to K nutrition. The need for a balanced application of NPK for higher yield in palak has been elucidated (Alur, 2017).

Leaf area and LAI were the highest in the treatment of six cuttings (h_3) followed by five cuttings (h_2) and the lowest in four harvests (h_1). It is interpreted that leaf cutting provides a pruning effect that encourages vegetative growth by the production of more number of leaves resulting in higher leaf area and LAI. The higher number of leaves in h_3 (33.5) compared to that in h_1 (26.7) as depicted in Fig. 5. These results are in agreement with the findings of Sarkar (2012) in water spinach. The combination $s_1n_1h_3$ recorded significantly the highest LAI. The better performance recorded in the above treatment is supported by the observations on yield per 10 m^2 (Fig. 6b)

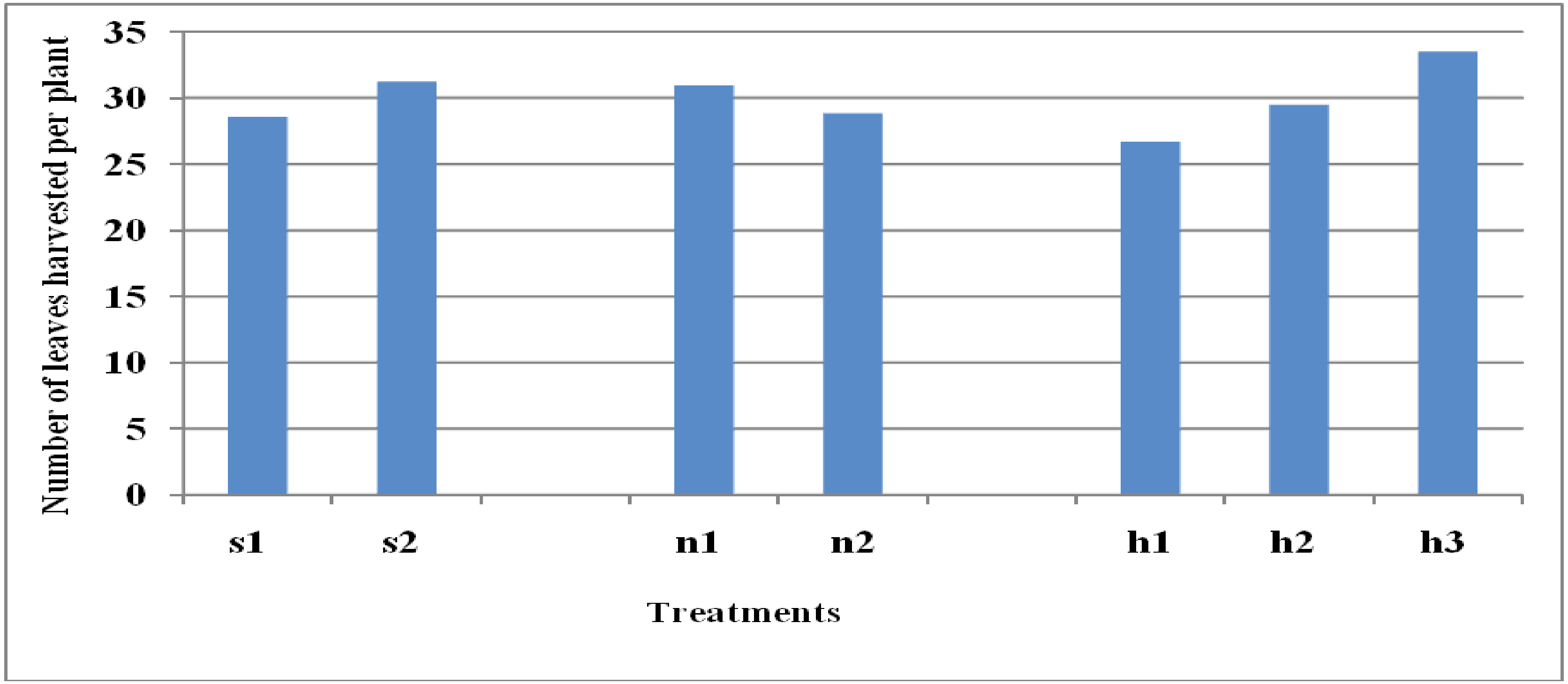

Fig. 5 Individual effects of spacing (S), nutrient management (N) and number of harvests (H) on number of leaves harvested per plant

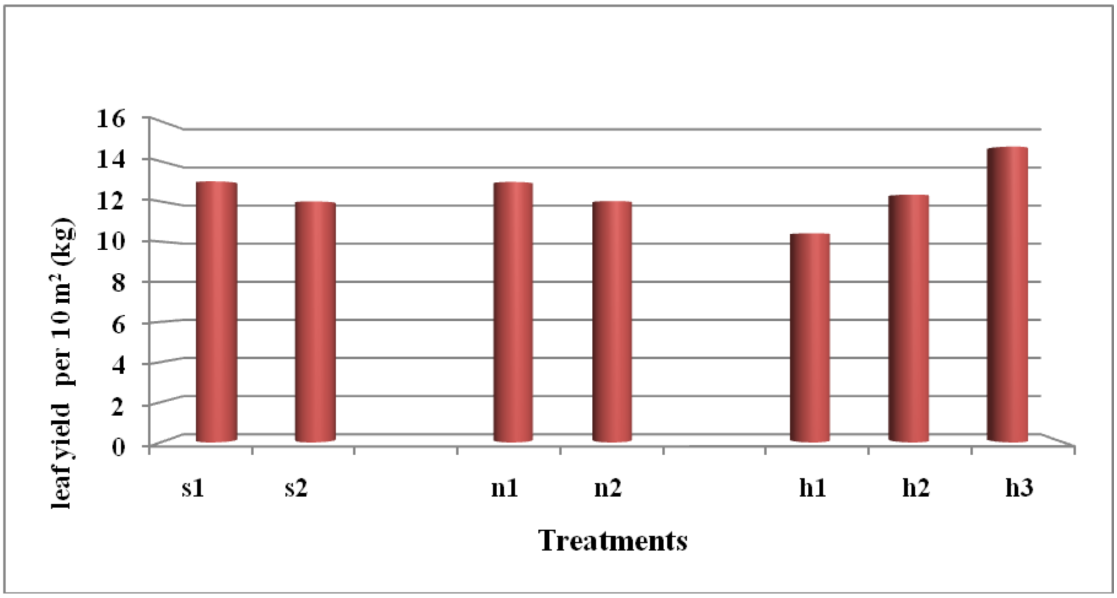

Fig. 6a Individual effects of spacing (S), nutrient management (N) and number of harvests (H) on leaf yield per 10 m^2

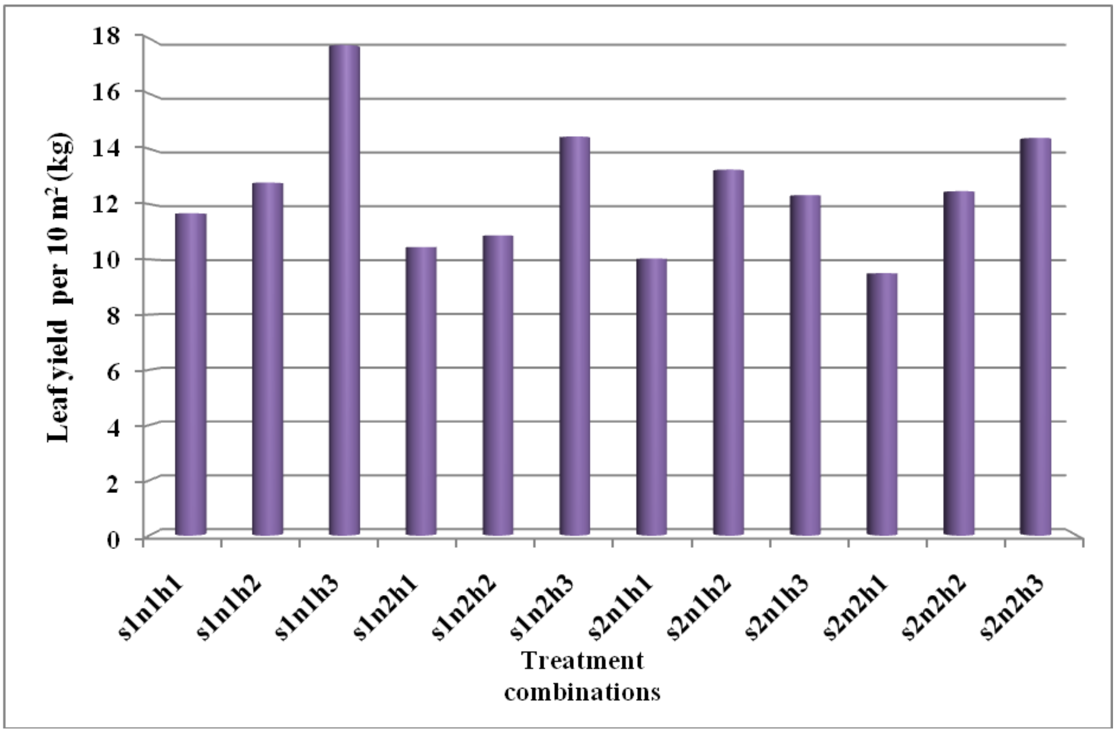

Fig. 6b Interaction effects, S x N x H on leaf yield per 10 m^2

Spacing ensures an equal chance for each plant to grow, thus plant density and spatial arrangement determines the competitive relationship in a plant community (Zimdahl, 1980). Galanopoulou-Sendouka *et al.* (1980) added that a high plant density hinders proper growth and development of individual plant and reduces yield, but it results in high yield per unit area due to increased plant population. Under wider spacing, inter plant competition for growth factors will be reduced thus favouring growth and enabling the plants to express their genetic potential. Better canopy development and radiation interception favour increased assimilation of photosynthates ultimately resulting in a higher yield and DMP. Similar results in spinach beet were reported by Mane (2003). On the other hand the total yield per unit area remained higher under closer spacing due to the higher plant population.

Yield attributes varied significantly with nutrient sources; inorganic nutrient sources (n_1) recorded superior values for number of leaves harvested per plant (31.0), yield per plant (102.41 g) and yield per 10 m^2 (12.97 kg).

Leafy greens, spinach beet in particular, is highly fertilizer responsive (Cantliffe, 1992), and hence demands large quantity of nutrients especially N. Nitrogen promotes growth, canopy development, radiation interception and photosynthates assimilation as it is the essential component of structural, metabolic and genetic constituents of cells (Milford *et al*., 2000). Vegetative growth is promoted by N application (Tisdale *et al.*, 1990) and hence is critical in leafy vegetables, as stem and leaves constitute the economic produce. Frequent harvests necessitate early and rapid re-growth and new flushes which calls for N fertilization as top dressing. Irrespective of the crop species, balanced fertilization requires prime attention. In spinach, Barker *et al*. (1971) and Magen (2008) documented that balanced NPK nutrition increased yield and DMP.

Jha and Jana (2009) also reported increased growth and yield in spinach beet with organic manure and RDF application. In the present study a basal dose of FYM @ 10 t $ha^{-1}$was applied uniformly in all treatments and this would have taken care of the soil physical and biological properties that favoured growth in the inorganic nutrition. The chemical fertilizers could cater the immediate requirements of N, P and

K in the early stages and also the re-growth after the repeated cuttings. Rapid availability of N through chemical fertilizers during active growth stage increases vegetative growth and ultimately results in higher yield and DMP (Solangi *et al.*, 2015). The findings of Bhore *et al.* (2000) and Mane *et al.* (2008) in palak and Mekha (2013) and Sarkar (2005) in amaranthus are in confirmation with the present result of increased green yield with inorganic nutrition.

In the case of number of harvests, yield attributes varied significantly with number of cuttings done. The yield attributing characters, *viz.*, number of leaves harvested per plant (33.5), yield per plant (107.22g), yield per 10 m^2 (14.73 kg) and DMP (35.76 g per plant) were significantly the highest for h_3 (six harvests) followed by h_2 (five harvests) and h_1 (four harvests). More number of harvests contributed significantly to the total yields realized per plant owing to the additional number of leaves harvested with each picking. The capacity of palak to regenerate and develop new flushes with successive harvests would be the plausible reason for the increased yield (Kasture *et al.*, 2002). The observations are in congruence with the findings of Jana *et al.* (1999) and Bharad *et al.* (2013).

The combination of wider spacing and six harvests *viz.*, s_2h_3 recorded significantly highest number of leaves harvested per plant while all other interactions were non significant. The leaf yield per plant was also unaffected by the combinations. However, yield per 10 m^2 was significantly the highest for the combinations involving 20 cm x 10 cm spacing, inorganic nutrient sources and six harvests *viz.*, s_1n_1, s_1h_3 and $s_1n_1h_3$. It is deduced that the effects of closer spacing, inorganic nutrition and more number of pickings were manifested in the interactions also, which led to the superior yield in this combination. The yield increase was nearly 30.6 per cent greater than wider spacing with inorganic nutrition and six harvests ($s_2n_1h_3$), 18.6 per cent greater than closer spacing, organic nutrition and six harvests ($s_1n_2h_3$), the second highest yield recorded (Fig. 6b).

The microclimate observations in the rain shelter recorded a lower light intensity, high air temperature and RH than in the open condition suggestive of a higher vegetative growth which was conducive for higher yield in spinach beet.

Comparatively better performance of spinach beet under protected conditions have been authenticated by Dixit (2007) and Alur (2017). Despite a rain fall of 74.3 mm received during the cropping season, the UV stabilized covering protected the crop from damage.

5.2 NUTRIENT UPTAKE AND QUALITY

Nutrient uptake is an indication of nutrient use efficiency by the crop and is dependent on the nutrient content and DMP of the crop. In the present study, nutrient uptake in the spinach beet varied significantly with spacing, nutrient sources and cutting management. N and P uptake were superior with wider spacing 30 cm x 10 cm. Significantly higher nutrient uptake values were registered with inorganic nutrition (n_1) and maximum number of harvests (h_3) as presented in Fig. 7.

The better uptake of N (1.48 g plant^{-1}) and P (0.101 g plant^{-1}) recorded with 30 cm x 10 cm (s_2) may be attributed to the higher yield and hence dry matter accumulation with wider spacing (Fig. 6a and 6b), in response to lower density stress as compared to closer spacing. Rajesh and Thanunathan (2003) based on their study stated that the higher nutrient uptake under wider spacing was due to the superior growth and yield attributes that were curtailed under closer spacing due to higher inter plant competition. Increased N uptake under wider spacing was reported by Nayak *et al*. (2014) in coriander. Generally when the N uptake is higher, the plants show a tendency to accumulate more P and this was observed in this study also. A balanced NPK absorption is important for proper growth and satisfactory yields, both in terms of quantity and quality, which is possible with balanced fertilisation (Rathore *et al*., 2008).

The nutrient uptake (N, P and K) found superior for plants fertilized with inorganic nutrient sources can be endorsed to the additive influence of increased dry matter accumulation and nutrient content, in response to enhanced nutrient availability from chemical fertilizers. Preetha (2003) in amaranthus and Bhattacharjee *et al*. (2017) in spinach also reported increased nutrient uptake with the application of chemical fertilizers.

With respect to the number of harvests, nutrient (N, P and K) uptake were the highest for plants with six harvests which is explained by the increased dry matter production owing to the more number of harvests done. This accords the reports of Waseem and Nadeem (2001) and Jabeen *et al.* (2018) in spinach.

Among the combinations, uptake was the highest for the combination involving 30 cm x 10 cm spacing, inorganic nutrient management and six harvests *viz.*, s_2n_1 (N), s_1h_3 (K) n_1h_3 (N and K), $s_2n_1h_2$ at par with $s_2n_1h_3$ (P), $s_1n_1h_3$ at par with $s_2n_1h_3$ (K), all of which corresponded to the individual effects of the factors contributing to higher yields and DMP in response to enhanced growth with wider spacing, readily available nutrients and more number of harvests.

The quality parameters assessed included protein, chlorophyll and vitamin (A and C) contents and these were estimated in the leaves of third and final harvests. It was evident that all the parameters were highest in the leaves of the third harvest and lower in the last harvested leaves. This is suggestive of a decline in the nutrient quality of the green leaves as crop duration advanced. Nutritional quality of a plant produce is decided by the balance of the biosynthetic and degradative reactions that take place in the cells. During growth and development, the biosynthetic pathways outpace the degradative ones leading to a net accumulation of nutrients. Though at the later stages *i.e.* senescence, the reverse takes place resulting in the loss of nutrients and hence lower contents. The evidences given by Shewfelt (1990) point to the fact that in crops there is a stage of horticultural maturity (optimal eating quality) and a stage of full biological maturity (physiological maturity) which are to be distinguished so as to resolve the harvesting stage. In spinach beet variety All Green, based on the results of the leaf quality analytical data it can be concluded that from the nutritional point of view, the leaves of the third harvest are superior, but when yields and economics are reckoned, the crop can be left for six harvests.

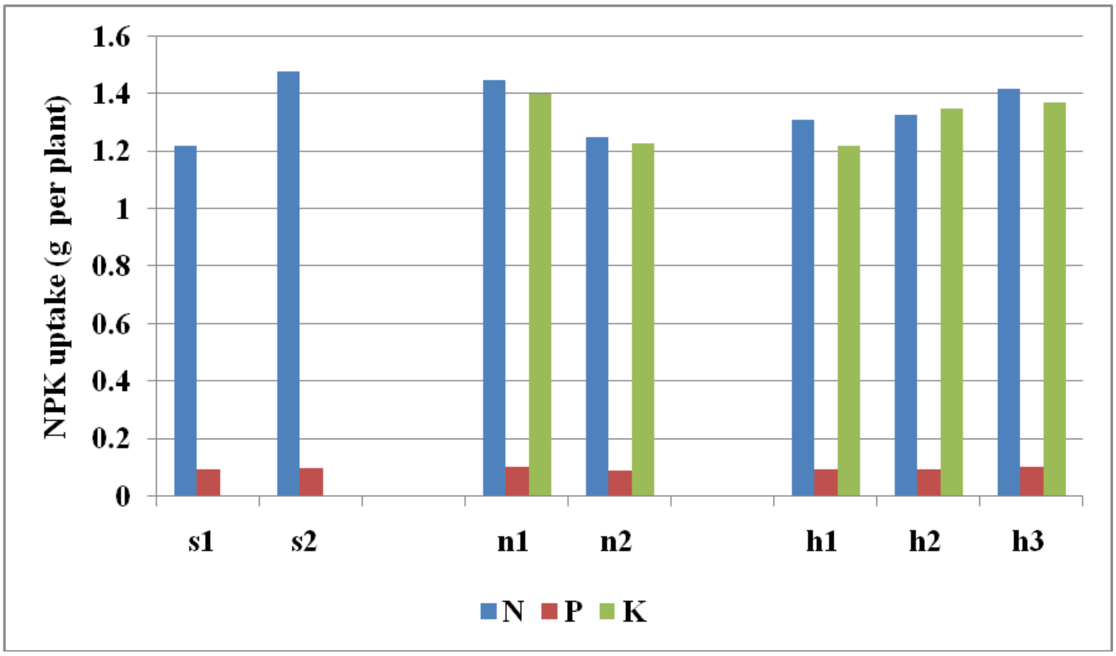

Fig. 7 Individual effects of spacing (S), nutrient management (N) and number of harvests on NPK uptake.

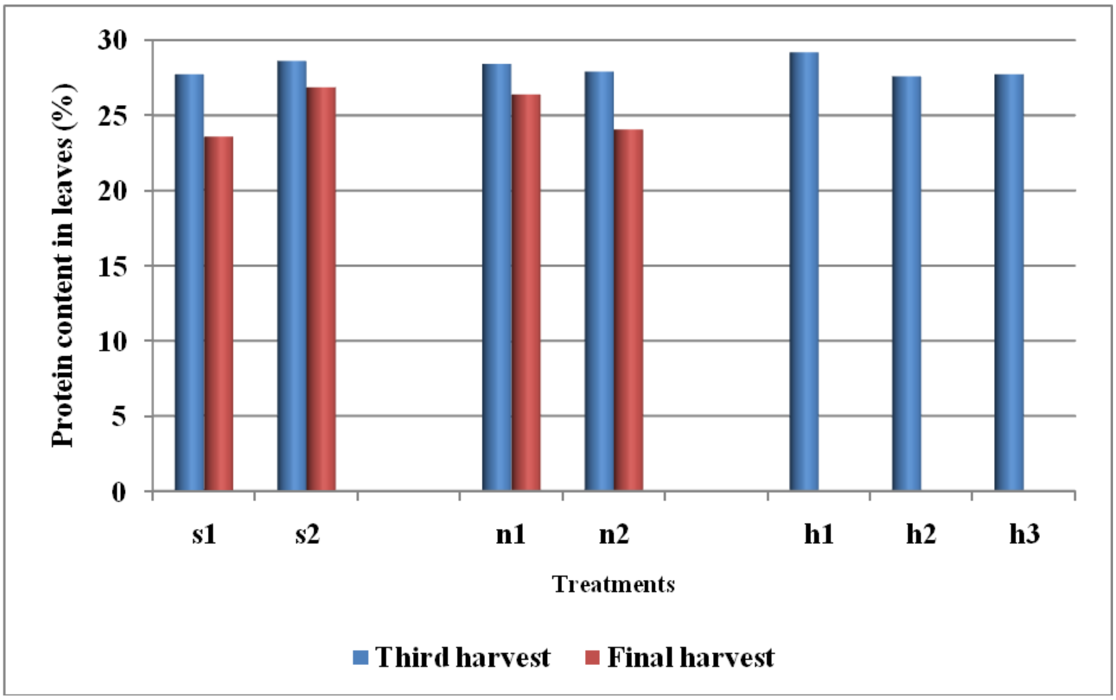

Fig. 8 Individual effects of spacing (S), nutrient management (N) and number of harvests on protein content of leaves

Protein content varied significantly with spacing and content was the highest for wider spacing while effect of spacing on chlorophyll content was found to be non significant. Significantly higher protein (28.43 per cent) and chlorophyll (1.51 mg g^{-1}) content were recorded for plants manured with inorganic nutrient sources (Fig. 8). Both protein and chlorophyll content declined in the leaves after the third harvest. The interactions involving wider spacing (s_2), inorganic nutrient sources (n_1) and four harvests (h_1) *viz.*, s_2n_1, s_2h_1, n_1h_1, $s_2n_1h_1$ at third harvest and s_2n_2 at par with s_2n_1 at final harvests for protein and n_1h_2 at par with n_1h_1 at third harvest, s_1n_2 at par with s_1n_1 at final harvests for chlorophyll were found superior. Among the three factor interactions, $s_2n_1h_1$ recorded the highest protein content, 30.98 per cent.

The increased protein content with wider spacing may be explained by the increased uptake benefitted by the reduced competition for resources and hence better growth (Fig. 7). Yarnia (2010) observed increased protein synthesis in leaves with wider spacing in amaranthus. As N is the chief structural constituent of protein and chlorophyll, the ease in N availability from urea would be responsible for the higher protein and chlorophyll content of plants with inorganic nutrient sources. This is in congruence with the reports of Singh *et al.* (1984) in amaranthus. Lester (2006) reported enhanced biological value of protein in organic produce even though the content is comparatively lower than that of conventionally grown produce. Higher chlorophyll content with chemical fertilizers over organic manures was reported in spinach beet (Gairola *et al.*, 2009; Bharad *et al.*, 2013). The same authors have elucidated the lowered chlorophyll content in spinach beet with increased number of harvests which support the results of the present study too.

The vitamin (A and C) content in spinach beet varied significantly with nutrient management and number of harvests (Fig. 9a and Fig 9b), however, were non significant with respect to levels of spacing. Significantly higher content of vitamin A and C (7.18 and 41.56 mg 100 g^{-1} respectively) were recorded for plants with organic nutrient management (n_2). The combination of 20 cm x 10 cm and organic nutrient management resulted in the highest vitamin A content at third harvest, but was at par with s_2n_2.

Among the nutritional quality parameters, vitamin content is critical as they are non nutrient bio active molecules that provide many specific nutritional and health benefits. The content largely depends on the genotype, cultural practices, method of harvest and post harvest handling (Lee and Kader, 2000). Spinach beet is a rich source of vitamin A and C. Asami *et al.* (2003) reported superiority of organic produce with respect to vitamins, minerals and polyphenols over conventionally grown plants. The enhanced levels of vitamins in organic produce may be due to the balanced and reliable supply of nutrients, both major and micro from organic sources resulting in favourable carbohydrate metabolism in plants. Vermicompost included among the organic sources is regarded as a complete fertilizer containing both macro and micro nutrients although in relatively lower quantities. Conversely the quantum used to supply the NPK dose of 80:40:80 kg would have added the micronutrients in satisfactory amounts for the crop. The positive response of availability of Ca, Mg and other micro nutrients on vitamin content of produce has been elucidated by Salunkhe and Desai (1988). Wang and Lin (2002) reported higher levels of vitamins and polyphenols in plants grown with compost. Similar reports on increased carotene and vitamin C content with organic nutrient sources were illustrated by Sheeba (2004) and Mekha (2013) in amaranthus. According to Sharma and Agarwal (2014), spinach grown with vermicompost contained 12.06 per cent more carotene than conventionally grown plants.

Quality of produce largely depends on the method of harvests; mechanical injuries such as bruises, cuts, abrasions during harvesting result in accelerated degradation of vitamins in plants (Gil *et al*., 2002). With increase in number of harvests, the extent and severity of injury or mechanical stress imposed on the plants increased which favoured the degradation of vitamins. This could further explain the lowest vitamin content in leaves harvested in the sixth cutting. Another possible reason for decrease in vitamin content may be the reduced nutrient availability to plants with successive harvests without replenishments. Bhore *et al*. (2000) and Bharad *et al.* (2013) reported similar trend of decreased ascorbic acid and carotene content with increased cuttings in palak.

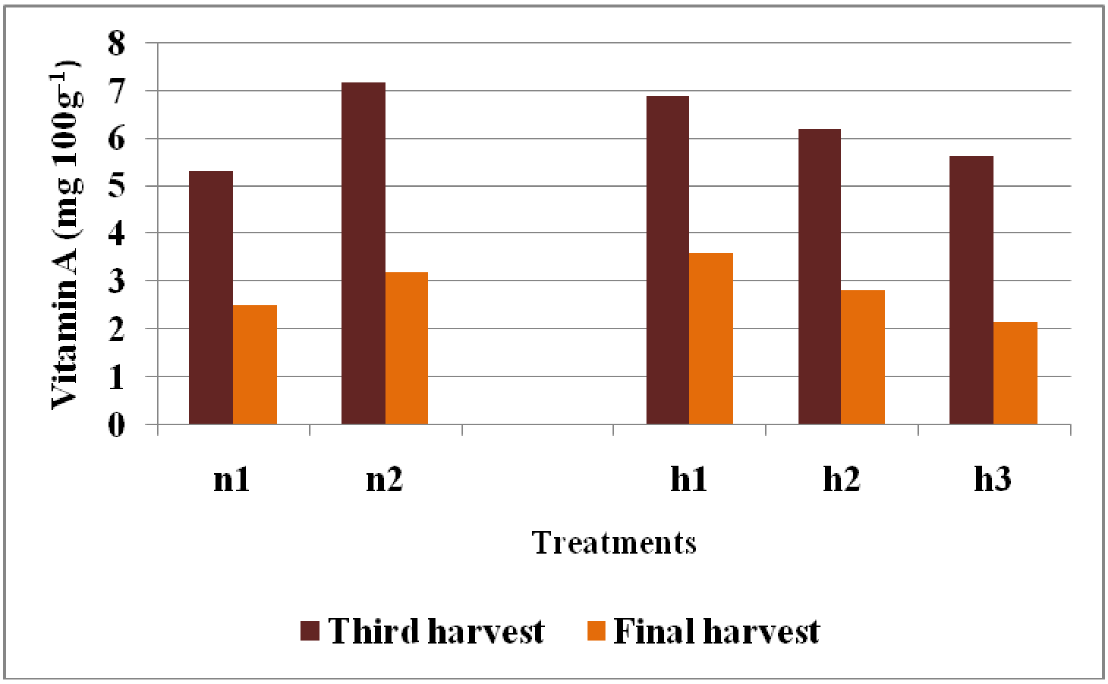

Fig. 9a Individual effects of nutrient management (N) and number of harvests (H) on vitamin A content of leaves

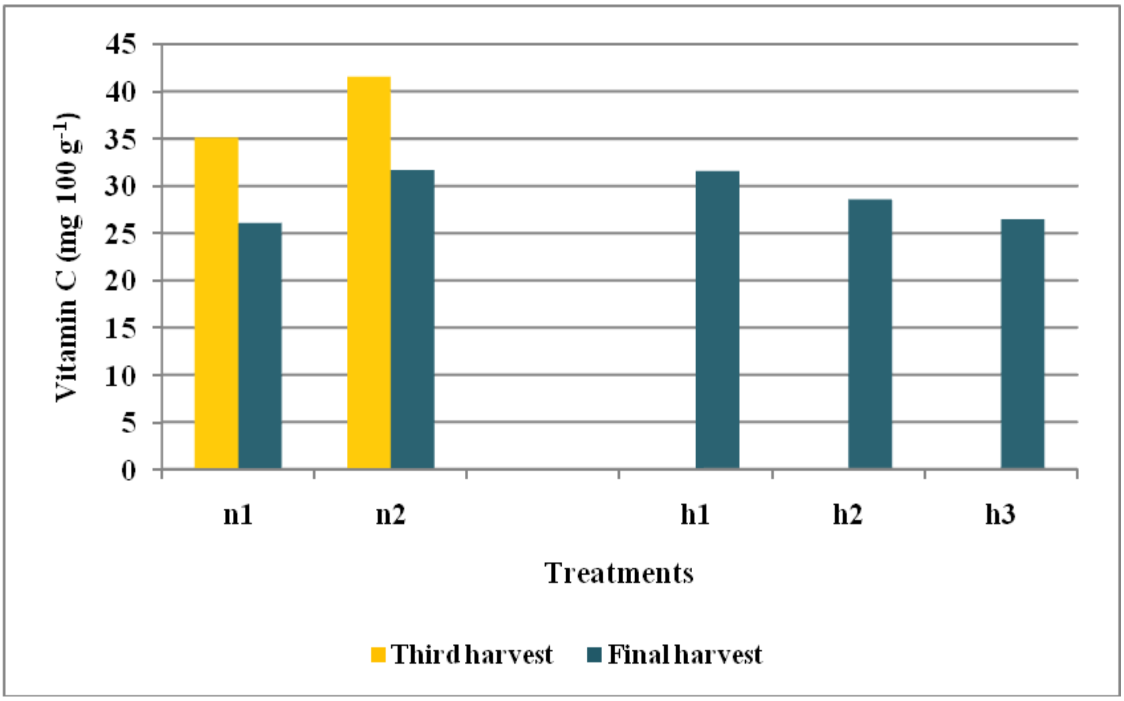

Fig. 9b Individual effects of nutrient management (N) and number of harvests (H) on vitamin C content of leaves

5.3 SOIL PROPERTIES

Soil chemical and biological properties showed significant variations with the treatments and were favourably enhanced after the experiment.

The effect of spacing was found to be significant for available P status alone and it was the highest under wider spacing. Even though the nutrient uptake per plant was higher under wider spacing, the DMP per unit area was higher under closer spacing as reflected in the yields (Fig. 6a, 6b). This resulted in increased nutrient uptake per unit area under closer spacing and may be the possible reason for lower available P content with closer spacing. Shukla *et al*. (2014) reported higher available P under wider spacing of plants, confirming the observation in this study.

Organic nutrient management enhanced the soil nutrient status in terms of organic C and available nutrient (NPK) content of soil after the experiment. The effect was non significant with respect to available P status and this was expected as the initial status was high.

The organic sources included in the study were vermicompost, AMF, rock phosphate and wood ash. Vermicompost, in addition to being a source of nutrients, contains plant growth promoting substances, enzymes, vitamins, mucus deposits etc. which contribute to improved soil physicochemical properties (Bano *et al*., 1987). Further, it adds organic matter to soil and promotes soil microbial activity resulting in a significantly higher organic C content as registered in n_2. Evidences on increased organic C content in soil with the addition of organic nutrient sources have been documented (Madhavi, 1992; Jyothi, 2006). It is understood that organic nutrient sources enhance the soil quality by improving structure, aeration, water holding capacity and soil biological properties (Rao and Chandra, 2005). This in turn favours the weathering of minerals and mineralization of organic complexes which resulted in the increased soil nutrient status. Thind *et al*. (1993) and Roy *et al*. (2009) have instantiated the enhancement of available NPK content in soil with organic nutrient management.

According to Rosen and Bierman (2005), nutrients from composts are more of residual nature indicative of the slow release property and additions to the soil fertility and this increased the status from the initial status. The nutrient dose of 80:40:80 kg NPK ha^{-1} were supplied with organic sources on equivalent basis, but biomass production and uptake were significantly lower in organic nutrition (Fig.7) implying the accumulation in soil. This, coupled with the mineralisation and solubilisation that accompanies enhanced microbial activity would have contributed to the higher NPK status under organic nutrition. The microbial count enumerated (Fig. 10) were also higher, substantiating the improved fertility status.

Exploring the changes with the different number of harvests, soil organic C and available K content in soil varied significantly, and it was non significant with respect to available N and P. In general, there was a decline in soil nutrient content with higher levels of harvests. It is interpreted that since palak was grown as a multi-cut crop, it demanded more amount of nutrients from soil for its re-growth after each harvest. The higher the number of harvests more would be the soil removal. Topdressing was continued only up to 60 DAS. The absorption of nutrients from soil, post harvest, for the new flushes, depleted nutrients in soil resulting in the decline. The lowest soil nutrient status (N and K) were registered in the treatment in which plants were harvested six times. Phosphorus status was initially high and the dynamics in soil depended on P buffering capacity, which is highly influenced by the nutrient additions and microbial activity. Hence the trend varied from that observed in N and K. Root activity and rhizospheric processes, critical for P solubilisation would have raised the P status to levels of non significance. Hejcman *et al*. (2010) reported decline in available NPK with frequent cuttings without fertilizer application and accords the present findings.

In agricultural ecosystems, there exists a two way interaction between the plants and soil microflora. The resident vegetation in a particular soil selectively determines the quantum and composition of soil microbes (Berg and Smalla, 2009) and this in turn interferes with the growth of plants. The management practices adopted have a prominent role in modifying the plant microbiome, both the diversity and activity (Zachow *et al.*, 2014).

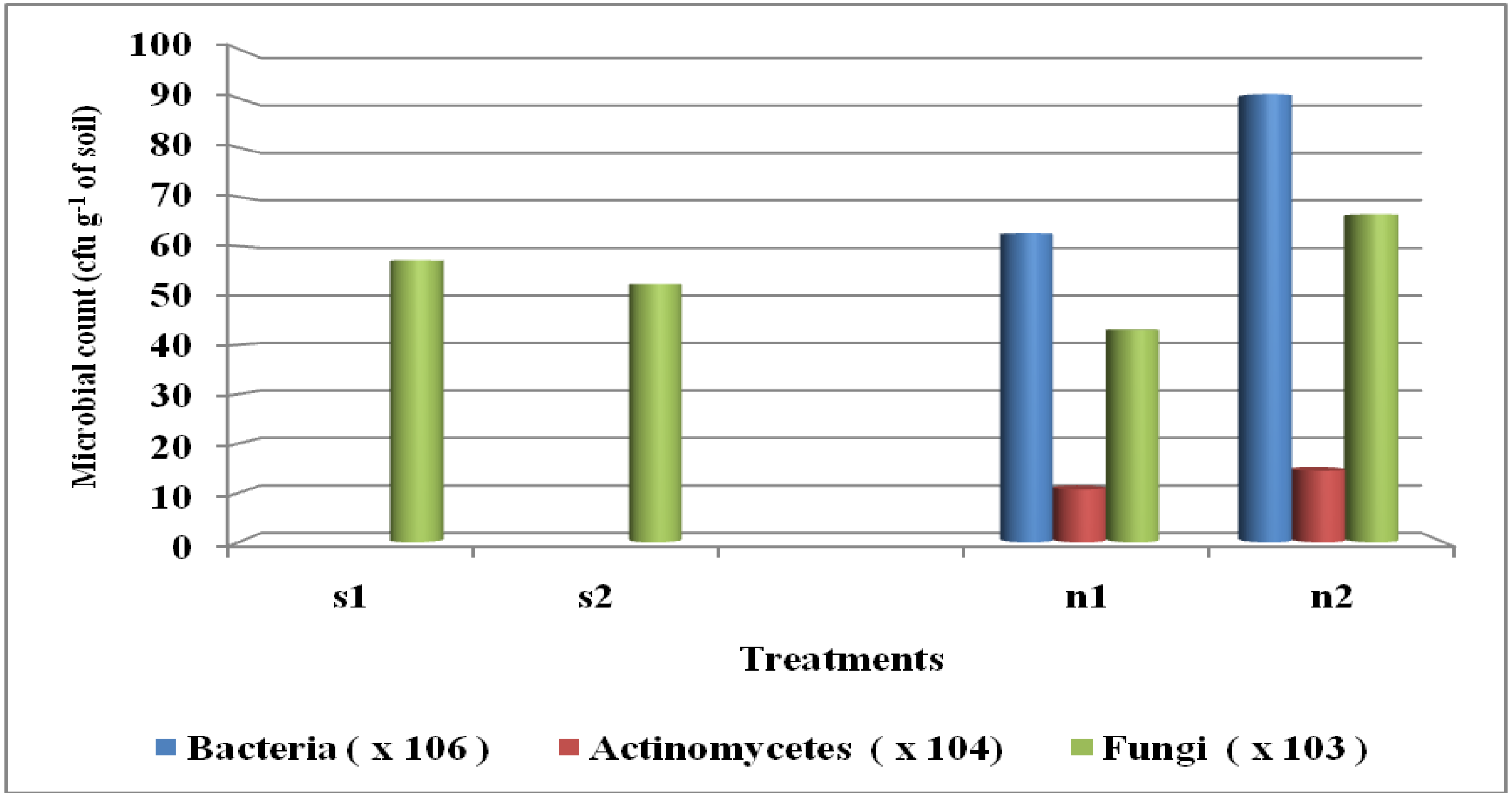

Fig. 10 Individual effects of spacing (S) and nutrient management (N) in microbial count of soil after the experiment

The variations due to the treatments were significant selectively, but the counts were found remarkably higher than the initial status. This clearly indicates the influence of cropping and management practices on the microbiome in soil. Roots form the nucleus around which all rhizospheric activities are orchestrated. In the presence of a crop, microbial activity in the soil, especially near the roots gets stimulated. Plant root exudates provide nutrition to rhizosphere microbes, thus increasing microbiological activity in the rhizosphere, which in turn stimulate plant growth (Khan, 2005). Specific microorganisms are enriched from the surrounding environment attracted by root exudates containing carbohydrates, proteins, and vitamins (Chaparro *et al.*, 2013). Consequent to these processes, each plant harbours a certain degree specific microbes. Further, the basal addition of FYM @10 t ha^{-1} uniformly in all plots would have contributed to the microbial counts on account of the microorganisms already present in them and the organic matter added to soil that promoted multiplication and growth.

The soil microbial population was favourably augmented by spacing, nutrient management and number of harvests. Significantly higher fungal population was registered with closer spacing while there is no marked variation in bacterial and actinomycete population with spacing. The higher fungal population under closer spacing may be due to the higher root density per unit soil volume as plant population was higher in closer spacing. Increased symbiotic association of mycorrhiza with higher plant density has been reported by Schroeder and Janos (2004).

The bacterial (90.8×10^6), actinomycete (14.5×10^4) and fungal (66.5×10^3) population were significantly higher for organically manured plots. The nutrient management practices exerted significant influence on all microbes enumerated. Organically manured plots (n_2) recorded significantly higher population of bacteria (90.8×10^6), actinomycetes (14.5×10^4) and fungi (66.5×10^3) per g soil. Krishnakumar *et al.* (2005) and Mekha (2013) reported higher microbial count in soil with organic nutrient management. Chemical fertilizer application recorded lower counts, but higher than the initial counts, as they were benefitted by the microorganisms in the FYM applied as basal dose and the root effects of spinach beet plants. On the other hand, organic nutrition had two distinct advantages over chemical fertilizers; firstly, the organic manure itself contains microorganisms and secondly, it contains organic substances that can be absorbed and utilised by the soil microorganisms thus promoting growth and proliferation. The organic nutrient sources used in the study *viz.*, vermicompost and AMF, both are microbe rich. Vermicompost is the product of earthworm degradation through ingestion and digestion and are reinforced by the microorganism in the gut of earthworms (Scheu, 1987). Das (2018) compared the microbial counts in naturally and vermicomposted leaf litters and reported the significantly higher population in the vermicomposted litter. Besides, vermicompost contained secondary and micronutrients which might have favoured the multiplication of micro organisms in soil with organic nutrient management (Kannan *et al.*, 2005). Root colonisation by mycorrhizal fungi occurs naturally in soil and is enhanced by the inoculation of AMF for P solubilisation. The additive effects contributed appreciably to the microbial counts in the organic nutrition. Liang *et al*. (2020) clearly demonstrated the increase in bacterial activity and diversity with bio organic fertilizer application. The findings of the study are in conformity with the earlier report of Schmidt *et al*. (2019). According to Zhao *et al.* (2018), the application of the bio organic fertilizers not only intensified the composition of the rhizosphere microbial community, but also altered it favourably, suppressing the pathogens and promoting plant quality.

The microbial population registered a comparative increase with increase in number of harvests with the highest count in plots harvested six times. The longer crop duration and presence of live roots with rhizosperic activities would have stimulated further multiplication and microbial activities. The interaction effect of host plant on soil microbial population becomes more prominent over time, as reported by Bakker *et al*. (2012)

In the case of interactions, the combinations involving organic nutrient management and six harvests *viz.*, n_2h_3 and s_2h_3 recorded the highest bacterial population. However, fungal counts were higher for combinations involving closer spacing, organic nutrient management and six harvests *viz.*, s_1n_2, s_1h_3 and n_2h_3 due to the reasons explained above.

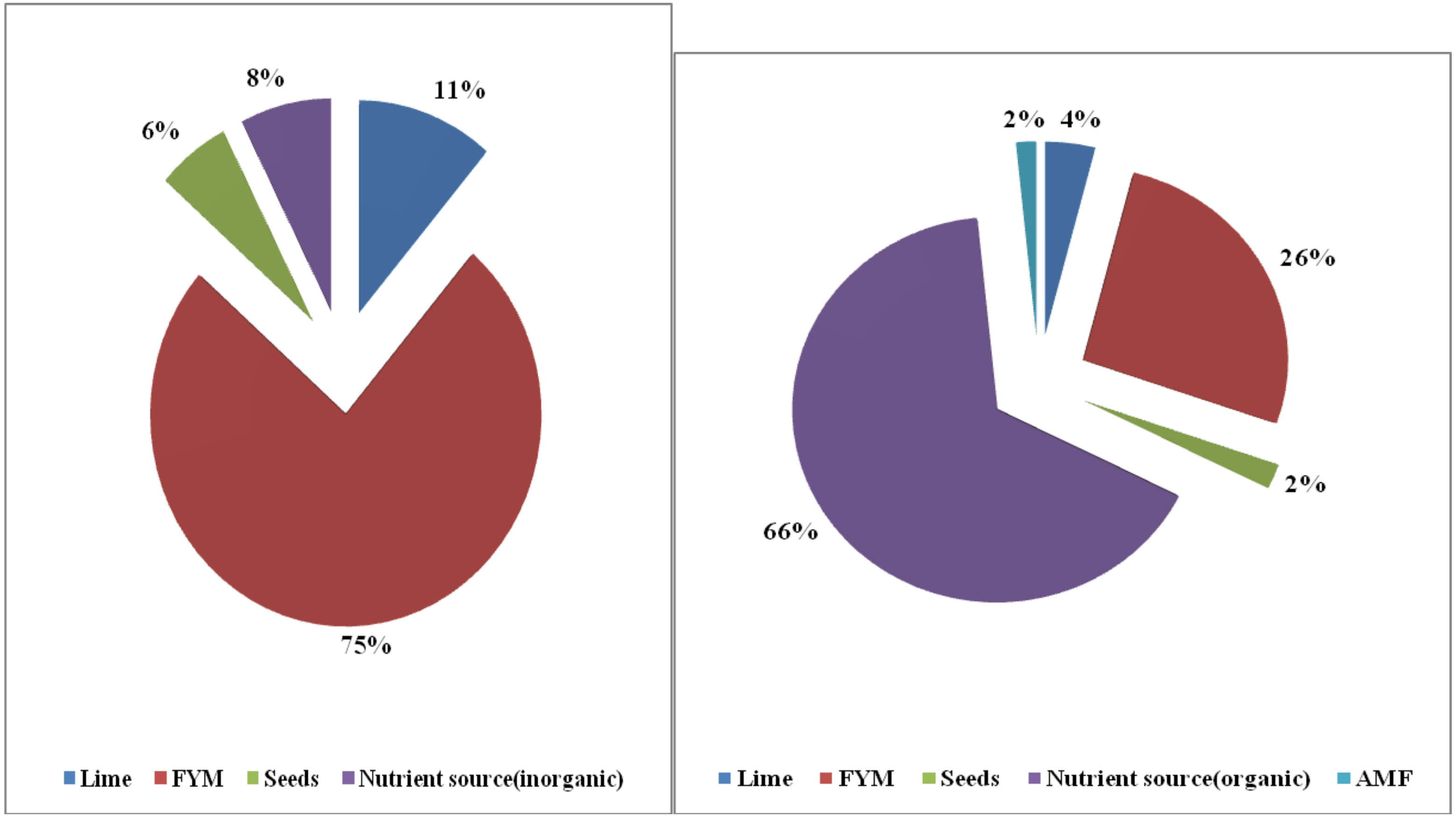

Fig.11 Cost of inputs of treatments with inorganic ($s_1n_1h_3$) and organic nutrient sources ($s_1n_2h_3$)

5.5 ECONOMICS OF CULTIVATION

Economic feasibility is a major concern while adopting newer agrotechniques. The economic analysis for different treatment combinations for an area of 10 m^2 revealed that a combination of 20 cm x 10 cm spacing, inorganic nutrient management and six harvests resulted in the highest gross income (₹ 888), net income (₹ 406) and BCR (1.84) followed by $s_1n_2h_3$ (20 cm x 10 cm + organic nutrient sources + six harvests) with a BCR of 1.47.

The higher economic benefits with the closer spacing, inorganic nutrient sources and six harvests may be due to the higher yields realized and lower cost incurred for the various individual factors.

Higher economic returns, under closer spacing is attributed to the increased yield per 10 m^2, as plant population is the major factor that determines the productivity in crops. Increased net returns and BCR with closer spacing was reported by Sharma and Prasad (1990) in fenugreek, Sarkar *et al*. (2014b) in water spinach and Diwan *et al.*(2018) in coriander.

Organic nutrient sources *i.e.* vermicompost being bulky with a low nutrient content (1.28% N, 0.48% P_2O_5 and 0.54% K_2O), were required in large quantities adding to the cost of cultivation (Fig. 11). Comparing the computed cost incurred for the different inputs, nearly 66 per cent of the cost of cultivation is for the organic nutrient inputs. It was only 8 per cent in inorganic nutrition. On comparison, the higher yields realised and lesser cost involved puts inorganic nutrition as economically viable. Higher economic returns with chemical fertilizer application over organic manures were reported in a comparative study on use of nutrient sources in amaranthus by Mekha (2013) in amaranthus.

Nevertheless, the BCR of organic nutrition was the second best and it is inferred that on farm or *in situ* production of the compost through resource recycling can make organic nutrition economically superior.

With increase in number of harvests the yield and returns increased without incurring any additional input cost. This explains the increased economic benefits in spinach beet with six cuttings. The results accord that of Baboo and Rana (1995) and Tiwari *et al.* (2002) who reported higher BCR with higher number of cuttings over single cutting.

Based on the above findings, it can be inferred that the agrotechniques spacing, nutrient management and number of harvests are eminent for economic yield, quality and soil properties. In spinach beet closer spacing was critical for sustained yield, chemical fertilizers proved to be economic in the present experiment, but in terms of quality, organic nutrition was found superior. Increasing the number of harvests is suitable for high yield and economics, however, for better quality of the produce, leaves of the third harvest were found better.

SUMMARY

6. SUMMARY

The experiment entitled "Standardization of agrotechniques in spinach beet (*Beta vulgaris* L. var. *bengalensis*)" was carried out under rain shelter condition at College of Agriculture, Vellayani during October 2019 to January 2020. The main objectives of the experiment were to standardize the planting geometry, nutrient management practice and number of harvests for economic yield and quality in spinach beet under rain shelter condition and to assess the effect on soil chemical and biological properties.

The 2 x 2 x 3 factorial experiment was laid out in randomized block design with 12 treatments in three replications using All Green as the test variety. The treatments included two spacings (s_1: 20 cm x 10 cm; s_2: 30 cm x 10 cm), two nutrient management practices (n_1: inorganic sources; n_2: organic sources) and three number of harvests (h_1: four harvests; h_2: five harvests; h_3: six harvests). The NPK dose of 80: 40: 80 kg ha^{-1} was given using organic and inorganic sources on N equivalent basis as per the treatments. The organic sources used were vermicompost (1.28% N, 0.48% P_2O_5 and 0.54% K_2O), rock phosphate (20 % P_2O_5), wood ash (6.03 % K_2O) and AMF, and the inorganic sources, Urea (46% N), Rajphos (20 % P_2O_5) and Muriate of potash (60 % K_2O). One fourth N and K, full P were given as basal, remaining N and K as top dressing in equal splits, 20 DAS and after first and second harvests. The crop was ready for the first harvest 40 DAS and subsequently harvests were done at 60, 70, 80, 95 and 105 DAS. The observations on growth, yield, quality and soil properties were statistically analysed and based on the results, salient findings of the experiment are summarized as follows.

Among the spacings tried, plants were taller in the 20 cm x 10 cm spacing at 30, 40, 60 and 70 DAS, and at final harvest, plants under wider spacing, 30 cm x 10 cm were significantly taller. Inorganic nutrient management (n_1) recorded significantly taller plants (18.05, 19.99 and 32.34 cm at 30, 40 and 60 DAS respectively). The maximum number of harvests registered the shortest plants at the final harvest stage (30.97 cm).

The interactions s_1n_1 (20 cm x 10 cm + inorganic nutrient sources) at 30 and 60 DAS and n_2h_3 (organic nutrient sources + six harvests) at par with n_1h_1, n_1h_2, n_2h_2 at 70 DAS registered maximum plant height.

Wider spacing, 30 cm x 10 cm recorded significantly highest leaf area (60 DAS and final harvest). Inorganic nutrient management resulted in significantly maximum leaf area at 40 and 70 DAS. Leaf area increased with number of harvests and the significantly highest means (321.2 and 356. 6 cm^2 per plant) at 60 DAS and final harvest respectively.

Leaf area was maximum for s_2n_1 (30 cm x 10 cm + inorganic nutrient sources) at par with s_2n_2, n_1h_2 and n_1h_3 at second, third and final harvests respectively.

LAI were significantly the highest for closer spacing, 20 cm x 10 cm, with values 1.39, 2.1 and 1.46 at first, third and final harvests respectively. Spinach beet plants with inorganic nutrition (n_2) recorded significantly superior LAI at 40 and 70 DAS. Plants with six harvests registered significantly superior LAI of 1.47 at final harvest.

Maximum LAI was recorded by n_1h_2 (inorganic sources + five harvests) at par with n_2h_3, n_1h_3 and n_1h_1 at 70 DAS. At final harvest, n_1h_3 (inorganic nutrient sources + six harvests) and $s_1n_1h_3$ (20 cm x 10 cm + inorganic nutrient sources + six harvests) recorded significantly superior LAI (1.67 and 1.93 respectively).

With regard to the root parameters, root length was the highest (21.39 cm) for the combination of 30 cm x 10 cm spacing, inorganic nutrition and five harvests ($s_2n_1h_2$) at par with $s_1n_1h_3$, s_1n_2h, $s_2n_2h_3$, $s_1n_2h_3$, and $s_2n_1h_1$. Root volume was the highest for plants with six harvests (5.02 mL) at par with h_2 (4.28 mL).

Yield attributes per plant *viz.*, number of leaves harvested per plant (31.2), leaf yield per plant (103.07 g) were significantly maximum under wider spacing, 30 cm x 10 cm while leaf yield per 10 m^2 was significantly the highest under 20 cm x 10 cm (13.00 kg).

Plants with inorganic nutrient management were significantly superior with respect to all yield attributes *viz.*, number of leaves harvested per plant (31.0), leaf yield per plant (102.41g) and leaf yield per 10 m^2 (12.97 kg).

With increase in number of harvests leaf yield also increased with the highest number of leaves harvested (33.5), leaf yield per plant (107.22 g) and leaf yield per 10 m^2 (14.73 kg) in plants with six harvests followed by five and four harvests.

The interactions s_1n_1 (20 cm x 10 cm + inorganic nutrient sources), s_1h_3 (20 cm x 10 cm + six harvests) and $s_1n_1h_3$ (20 cm x 10 cm + inorganic nutrient sources + six harvests) recorded the highest and significantly superior yield per 10 m^2. The number of leaves harvested was significantly the highest for the interaction s_2h_3 (30 cm x 10 cm + six harvests).

The per plant DMP varied significantly with the main effects and it was the highest under wider spacing (34.54 g), inorganic nutrition (34.36 g) and six harvests (35.76 g). Nitrogen and P uptake were significantly the highest under 30 cm x 10 cm spacing with values 1.48 and 0.101 g per plant respectively. Significantly higher nutrient uptake (1.45, 0.105 and 1.40 g per plant of NPK respectively) was registered with inorganic nutrition, n_1. Spinach beet with maximum number of harvests registered the highest uptake of N (1.42 g per plant), P (0.102 g per plant) and K (1.37 g per plant).

The combination, s_2n_1 (30 cm x 10 cm + inorganic nutrient sources) was at par with s_2n_2, n_1h_3 (inorganic sources + six harvests) for N uptake, $s_2n_1h_2$ (30 cm x 10 cm + inorganic sources+ five harvests) at par with $s_2n_1h_3$ and $s_1n_1h_3$ for P uptake and s_1h_3 (20 cm x 10 cm + six harvests) at par with s_2h_2 (organic sources + five harvests), n_1h_3 (inorganic sources + six harvests) and $s_1n_1h_3$ (20 cm x 10 cm + inorganic nutrient sources + six harvests) for K uptake recorded the highest mean.

Spacing exerted significant influence on the protein content of leaves and the highest content was recorded under wider spacing s_2, the value being 28.63 and 26.87 per cent in the leaves at third and final harvests respectively. Protein (third and final harvests) and chlorophyll (third harvest) content were significantly the highest for plants fertilized with inorganic nutrient sources (n_1). The contents were maximum in leaves of third harvests (29.19 per cent and 1.47 mg g^{-1}) and significantly the lowest in the leaves of sixth harvest (h_3).

In the case of protein, the interactions s_2n_1 (30 cm x 10 cm + inorganic nutrient sources), s_2h_1 (30 cm x 10 cm + four harvests), n_1h_1 (inorganic nutrient sources + four harvests) at par with n_2h_1 and $s_2n_1h_1$ recorded superior values at third harvest and s_2n_2 recorded the highest content at final harvest.

The combinations n_1h_2 (inorganic sources + five harvests) at third harvest and s_1n_2 at final harvests recorded the significantly highest chlorophyll content.

The effect of spacing on vitamin content was non significant while it varied significantly with nutrient management both at third and final harvests stage and the contents were the highest for plants with organic nutrient management (n_2) .Vitamin A and C decreased with increase in number of harvests and plants with six harvests (h_3) recorded significantly inferior values (2.15 and 26.49 mg 100 g^{-1} respectively).

Among interactions, s_1n_2 (20 cm x 10 cm+ organic nutrient sources) registered maximum vitamin A content at third harvest and was at par with s_2n_2 (30 cm x 10 cm + organic sources).

The results on the changes in soil chemical properties after the experiment revealed the effect of spacing to be significant only with respect to available P content and the highest P status (55.02 kg ha^{-1}) was recorded for the wider spacing s_2. Plots with organic nutrient management (n_2) registered the highest organic C (1.22 %), available N and K (226.4 and 190.71 kg ha^{-1} respectively) status. Soil organic C (1.24 %) and available K (191.06 kg ha^{-1}) content were significantly the highest for plots in which plants harvested four times (h_1).

The interactions s_2n_1 (30 cm x 10 cm + inorganic nutrient management) for available P and s_1h_1, n_2h_1 and $s_1n_2h_1$ for available K recorded significantly the highest mean values.

Soil microbial population varied significantly with the main factors. Spacing recorded significant influence on fungal counts with the highest count under closer spacing (s_1), 57.2 x 10^3 cfu g^{-1} soil. Significantly higher counts of bacteria (90.8 x 10^6), actinomycetes (14.5 x 10^4 cfu g^{-1} soil) and fungi (66.5 x 10^3 cfu g^{-1} soil) were recorded with organic nutrient management (n_2).

Among the combinations bacterial counts were highest in s_2h_3, n_2h_3 and fungal counts were found superior in s_1h_3 and n_2h_3.

Economic analysis revealed that gross and net income from 10 m^2 and BCR were the highest for the combination of $s_1n_1h_3$ (20 cm x 10 cm + inorganic nutrient sources + six harvests), the values being ₹888, ₹406 and 1.84 respectively which was followed by the combination $s_1n_2h_3$ (20 cm x 10 cm + organic nutrient sources + six harvests).

Based on the findings of the study, it can be concluded that

- The most suitable combination for cultivation of spinach beet under rain shelter condition for economic yield includes a spacing of 20 cm x 10 cm, application of NPK @ 80: 40: 80 kg ha^{-1} through inorganic sources and harvesting the crop six times
- Organic nutrition proved to be superior with respect to quality parameters (vitamin A & C), with highest content in the leaves of third harvest.
- Soil chemical and biological properties were favourably influenced and higher values were with organic nutrient management

Future line of work

- Inclusion of consortium biofertilizers and integrated nutrient management strategies for economic yield and quality in leafy vegetables
- Root studies and rhizospheric effects of spinach beet
- Foliar nutrition and use of organic growth promoters
- Fertigation to enhance nutrient use efficiency and reduce labour cost for irrigation under rain shelter conditions

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7. REFERENCES

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APPENDICES

APPENDIX I

Weather parameters during the cropping period

(22October 2019- 28 January 2020)

Standard week	Mean temperature (^oC)		Mean RH (%)		Rainfall (mm)	Sunshine (h)
	Max	Min	Max	Min		
2019						
43(22 Oct- 28 Oct)	30.3	23.6	91.3	77.7	6.1	0.8
44(29 Oct- 4 Nov)	28.8	24.0	95.0	78.7	15.1	4.7
45(05 Nov- 11 Nov)	32.5	24.8	89.3	68.1	0.0	9.0
46(12 Nov- 18 Nov	32.5	24.6	90.7	67.4	1.3	8.1
47(19 Nov- 25 Nov)	32.1	24.3	92.4	74.4	7.1	5.6
48(26 Nov- 2 Dec)	32.6	24.5	94.0	69.1	4.4	6.2
49(3 Dec- 9 Dec)	32.0	24.1	91.3	69.6	1.8	5.4
50(10 Dec- 16 Dec)	32.2	23.6	91.0	70.9	7.6	0.6
51(17 Dec- 23 Dec)	31.4	23.9	92.9	72.4	5.9	2.4
52(24 Dec- 31 Dec)	31.9	23.7	92.8	69.0	7.6	0.0
2020						
1(1 Jan – 7 Jan)	32.2	24.1	92.3	66.1	0.0	8.8
2(8 Jan- 14 Jan)	32.0	22.7	93.4	66.3	6.4	7.8
3(15 Jan – 21 Jan)	32.2	22.5	92.3	63.7	1.4	8.3
4(22 Jan- 28 Jan)	32.7	23.0	91.4	64.1	9.6	0.0

APPENDIX II

Microclimate observations during the cropping period

(22 October 2019- January 2020

Standard weeks	Air temperature (^{o}C)	Soil temperature (^{o}C)	RH (%)	Light intensity (k lux)
2019				
43(22 Oct- 28 Oct)	30.1	27.3	91.2	12.8
44(29 Oct- 4 Nov)	30.2	28.2	83.0	10.2
45(05 Nov- 11 Nov)	32.2	28.3	81.0	14.3
46(12 Nov- 18 Nov	32.3	28.2	78.0	17.6
47(19 Nov- 25 Nov)	33.2	26.2	89.8	16.3
48(26 Nov- 2 Dec)	32.3	29.2	88.8	15.6
49(3 Dec- 9 Dec)	33.4	28.5	88.2	14.9
50(10 Dec- 16 Dec)	34.3	29.4	81.2	17.9
51(17 Dec- 23 Dec)	32.7	27.3	87.3	14.3
52(24 Dec- 31 Dec)	33.2	26.2	92.1	12.5
2020				
1(1 Jan – 7 Jan)	31.7	28.2	85.0	15.2
2(8 Jan- 14 Jan)	31.6	27.5	77.2	13.2
3(15 Jan – 21 Jan)	32.5	26.5	78.2	12.7
4(22 Jan- 28 Jan)	33.5	27.8	83.6	14.4

APPEDINX – III

Average input costs and marketing price of produce

Items	Cost (₹)
Inputs	
Seeds	70 kg^{-1}
Manures and fertilizers	
FYM	5 kg^{-1}
Urea	8 kg^{-1}
Rock phosphate	12 kg^{-1}
Muriate of potash	20 kg^{-1}
Vermicompost	20 kg^{-1}
Lime	30 kg^{-1}
AMF	85 kg^{-1}
Labour cost	
Men	700 day^{-1}
Women	500 day^{-1}
Produce	
Market price of spinach beet	50kg^{-1} 60 kg^{-1} (Organic)

STANDARDIZATION OF AGROTECHNIQUES IN SPINACH BEET (*Beta vulgaris* L. var. *bengalensis*)

by

SRUTHY A B

(2018-11-014)

ABSTRACT

Submitted in partial fulfillment of the requirement for the degree of

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DEPARTMENT OF AGRONOMY

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VELLAYANI, THIRUVANANTHAPURAM - 695522

KERALA, INDIA

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ABSTRACT

The study entitled "Standardization of agrotechniques in spinach beet (*Beta vulgaris* L. var. *bengalensis*)" was carried out at College of Agriculture, Vellayani, to standardize the planting geometry, nutrient management practice and number of harvests for economic yield and quality in spinach beet under rain shelter condition and to assess the effect on soil chemical and biological properties. The experiment was laid out in randomized block design in three replications during October 2019 to January 2020 with the variety All Green. The treatments included two spacings (s_1: 20 cm x 10 cm; s_2: 30 cm x 10 cm), two nutrient management practices (n_1: inorganic sources; n_2: organic sources) and three number of harvests (h_1: four harvests; h_2: five harvests; h_3: six harvests). The NPK dose adopted was 80:40: 80 kg ha^{-1}, one fourth N and K, full P were given as basal, remaining N and K, in splits as top dressing, 20 days after sowing (DAS) and after each harvest. The organic sources used were vermicompost, rock phosphate, arbscular mycorhizhal fungi (AMF) and wood ash, and the inorganic sources, urea, rajphos and muriate of potash.

The results of the experiment revealed that among the spacings tried, plant height (30, 40, 60 and 70 DAS), leaf area index (LAI) and leaf yield per 10 m^2 were higher in the closer spacing, while per plant leaf area, number of leaves harvested and yields were significantly the highest in the wider spacing, s_2. Among the nutrient sources, plant height (30, 40 and 60 DAS), leaf area, LAI and leaf yield were significantly higher in inorganic nutrient management. Leaf area, LAI and leaf yields were significantly the highest for the treatment with six harvests (h_3) followed by h_2 and h_1.

The interaction effects of S x N and S x H on leaf yields were significant. Among S x N interactions, s_1n_1 recorded significantly higher leaf yield per 10 m^2 (14.07 kg) and among the S x H interactions, s_2h_3 recorded the highest leaf yield per plant (111.56 g) whereas s_1h_3 showed the highest leaf yield per 10 m^2 (16.10 kg). The treatment combination $s_1n_1h_3$ recorded the highest LAI (1.93) and leaf yield per 10 m^2 (17.76 kg).

Nutrient uptake (N, P and K) were the highest in s_2, n_1 and h_3. Quality parameters (vitamins A and C, protein and chlorophyll content) were comparatively higher in the leaves of third harvest. Vitamin A and C content were highest in n_2 while protein and chlorophyll content were higher in n_1. S x N x H interaction was significant for the protein content alone.

The soil properties did not show significant variations with spacing except available P status, which was higher in s_2. Organic C, available N and K status were significantly higher in n_2 and declined with the increase in number of harvests, higher contents were recorded in h_1. The combination of $s_1n_2h_1$ registered the highest available K status in soil. Soil microbial counts were significantly higher for n_2 and the variations in fungal counts were significant for S x N, S x H and N x H interactions.

Economic analysis revealed that gross and net income from 10 m^2 and benefit cost ratios were the highest for the combination of closer spacing, inorganic nutrient management and six harvest, $s_1n_1h_3$, the values being (₹888, ₹ 406 and 1.84 respectively).

Based on the results, the most suitable combination of agro techniques for economic yield in spinach beet under rain shelter condition include, closer spacing of 20 cm x 10 cm (s_1), NPK dose of 80: 40: 80 kg ha^{-1} through inorganic sources (n_1) and six harvests (h_3). Considering the quality (vitamin A and C), organic nutrition (n_2) proved to be superior and contents were the highest in the leaves of third harvest. The treatment combinations favourably influenced the soil nutrient status and microbial counts, higher values were recorded for organic nutrient management.

സംഗ്രഹം

പാലക് ചീരയിലെ കാർഷിക പ്രവർത്തി രീതി ക്രമീകരണം എന്ന വിഷയത്തിൽ വെള്ളായണി കാർഷിക കോളേജിലെ വിള പരിപാലന വിഭാഗത്തിൽ 2019 ഒക്ടോബര് മുതൽ 2020 ജനുവരി വരെ ഒരു ഗവേഷണ പഠനം നടത്തുകയുണ്ടായി. മഴമറയിലെ പാലക് ചീര കൃഷിയ്ക്ക് അനുയോജ്യവും ലാഭകരവുമായ കാർഷിക മുറകൾ- ഇടയകലം, വള പ്രയോഗ രീതി, വിളവെടുപ്പിന്റെ എണ്ണം എന്നിവ സ്ഥിതീകരിക്കുക, തുടർന്നുണ്ടാകുന്ന മണ്ണിന്റെ രാസ ജൈവ വ്യതിയാനങ്ങൾ പരിശോധിക്കുക എന്നിവയായിരുന്നു പഠനത്തിന്റെ പ്രധാന ലക്ഷ്യങ്ങൾ. പാലക് ഇനമായ 'ഓൾ ഗ്രീൻ ' ഉപയോഗിച്ച് നടത്തിയ പഠനത്തിൽ രണ്ടു വ്യത്യസ്ത ഇടയകലം (20 സെ. മി. x 10 സെ. മി, 30 സെ. മി. x 10 സെ. മി.), 80: 40: 80 കി. ഗ്രാം NPK /ഹെക്ടറിന് എന്നതിന് രണ്ടു വള പ്രയോഗ രീതി (രാസവള പ്രയോഗം, ജൈവ വള പ്രയോഗം), മൂന്നു വിളവെടുപ്പുകളുടെ എണ്ണം (നാലു, അഞ്ചു, ആറു) ഉപയോഗിച്ച് റാണ്ഡമയിസ്ഡ് ബ്ലോക്ക് ഡിസൈനിൽ, മൂന്നു പ്രാവശ്യം ആവർത്തിച്ചാണ് പഠനം നടത്തിയത്.

പ്രസ്തുത പരീക്ഷണത്തിൽ ചെടികളുടെ ഉയരം, 10 ചതുരശ്ര മി. നിന്നുമുള്ള ഇലകളുടെ വിളവ് എന്നിവ 20 സെ മി. x 10 സെ മി. ഇടയകലത്തിൽ കൂടുതലായി തെളിഞ്ഞപ്പോൾ, ഒരു ചെടിയിൽ നിന്നും വിളവെടുത്ത ഇലകളുടെ എണ്ണം, തൂക്കം, ആകെ ഇലകളുടെ വിസ്തീർണം എന്നിവ 20 സെ. മി. x 10 സെ. മി. ഇടയകലത്തിലാണ് കൂടുതലായി കണ്ടത്. പാലക് ചീരയിലെ വിളവിനു ജൈവ വള പ്രയോഗത്തെക്കാൾ രാസവള പ്രയോഗം മികച്ചതായി കണ്ടെത്തി. വിളവെടുപ്പിന്റെ എണ്ണത്തിനനുസൃതമായി ഇലകളുടെ വിസ്തീർണവും, വിളവും കൂടുന്നതായും കണ്ടെത്തി.

20 സെ മി. x 10 സെ. മി. ഇടയകലത്തിൽ വളർത്തിയ ചെടികളിൽ രാസവളപ്രയോഗത്തോടൊപ്പം ആറു തവണ വിളവെടുപ്പ് നടത്തിയപ്പോൾ, 10 ചതുരശ്ര മി. നിന്നും വിളവെടുത്ത ഇലകളുടെ തൂക്കം കൂടുതലായി കാണപ്പെട്ടു.

30 സെ. മി. x 10 സെ. മി. ഇടയകലവും, രാസവളപ്രയോഗവും, ആറു തവണ വിളവെടുപ്പ് നടത്തിയ ചെടികളിൽ മൂലകങ്ങളുടെ ആഗിരണം കൂടുതലായും, ഇലകളുടെ പോഷക മൂല്യം (ജീവകം, മാംസ്യം, ഹരിതകം)

മൂന്നാമത്തെ വിളവെടുപ്പിലെ ഇലകളിൽ മികച്ചതായി കണ്ടെത്തി. ജൈവ സ്രോതസുപയോഗിച്ചു വള പ്രയോഗം നടത്തിയ ചെടികളിൽ ജീവകത്തിന്റെ അളവ് കൂടുതലായി കണ്ടെത്തിയപ്പോൾ മാംസ്യത്തിന്റെയും ഹരിതകത്തിന്റെയും അളവ് രാസവള പ്രയോഗം നടത്തിയ ചെടികളിലായിരുന്നു മികച്ചത്.

പാലക് കൃഷിയ്ക്കു ശേഷമുള്ള മണ്ണിലെ ജൈവ കാർബൺ, നൈട്രജൻ, പൊട്ടാസ്യം എന്നിവയുടെയും സൂക്ഷ്മ ജീവികളുടെയും അളവ് ജൈവ കൃഷിയിൽ കൂടുതലായി കാണപ്പെട്ടു. വിളവെടുപ്പിന്റെ എണ്ണം കൂടുന്നതിനനുസരിച്ചു മണ്ണിലെ മൂലകങ്ങളുടെ തോത് കുറയുന്നതായി കണ്ടെത്തി.

മേൽ പറഞ്ഞ പരീക്ഷണ ഫലങ്ങളുടെ അടിസ്ഥാനത്തിൽ, 20 സെ മി x 10 സെ മി. ഇടയകലവും, രാസവള പ്രയോഗത്തോടൊപ്പം ആറു വിളവെടുപ്പും മഴ മറയിലെ പാലക് കൃഷിയ്ക്ക് ഏറ്റവും അനുയോജ്യവും ലാഭകരവുമായി സ്ഥിരീകരിക്കാം. ഇലകളുടെ പോഷക മൂല്യം കണക്കിലെടുക്കുമ്പോൾ ജൈവ വള പ്രയോഗവും മൂന്നു വിളവെടുപ്പുമാണ് ഏറ്റവും അനുയോജ്യം. പാലക്കിലെ ജൈവ കൃഷി രീതി മണ്ണിന്റെഫലഭൂയിഷ്ടിക്കും സൂക്ഷ്മാണുക്കളുടെ വളർച്ചയ്ക്കും ഉത്തമമായി തെളിഞ്ഞു.