DETERMINATION OF OPTIMUM LEAF AREA AND PRODUCTIVE TILLERS FOR YIELD POTENTIAL OF FINGER MILLET (*Eleusine coracana* (L.) Gaertn.)

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in

CROP PHYSIOLOGY

BENGALURU **SEPTEMBER, 2018**

Affectionately Dedicated to

My Respected Parents

M.K. Samiulla,

Fouziya Banu

and

My beloved brother

Mr. Naveed Anjum.

DEPARTMENT OF CROP PHYSIOLOGY
UNIVERSITY OF AGRICULTURAL SCIENCES
BENGALURU – 560 065

CERTIFICATE

This is to certify that the thesis entitled **"DETERMINATION OF OPTIMUM LEAF AREA AND PRODUCTIVE TILLERS FOR YIELD POTENTIAL OF FINGER MILLET (*ELEUSINE CORACANA* (L) GAERTN.)"** submitted by **Mr. MUJAHID ANJUM.,** ID. No. **PALB 6211** for the partial fulfillment of the degree of **MASTER OF SCIENCE (Agriculture)** in **CROP PHYSIOLOGY** to the University of Agricultural Sciences, GKVK, Bengaluru- 560 065. This is a *bona-fide* record of research work done by him during the period of his study in this University, under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associate-ship, fellowship or other similar titles.

Bengaluru
September, 2018

Y.A. NANJA REDDY
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October 2018 **Mujahid Anjum**

DETERMINATION OF OPTIMUM LEAF AREA AND PRODUCTIVE TILLERS FOR YIELD POTENTIAL OF FINGER MILLET (*Eleusine coracana* (*L*) Gaertn.)

MUJAHID ANJUM

ABSTRACT

Finger millet is cultivated as rainfed crop under poor and marginal lands and; the yield potential of the crop has reached a plateau. One of the strategies for further improvement in yield potential is through the physiological approach. In this view, two experiments were conducted at Field Unit, ZARS, UAS, GKVK, Bengaluru. The first experiment was conducted using three finger millet genotypes (GPU-28, GE-292 and GE-199) in different plant spacings to arrive at different leaf area per plant. Maximum grain yield (754.7 g m^{-2}) with a maximum LAI of 7.5 was obtained in the spacing of 15 cm x 10 cm as compared to the recommended spacing of 22.5 cm x 10 cm. The productive tillers per unit area were increased with an increased plant density, however, 190.9 tillers per square meter at 15 cm x 10 cm produced highest grain yield. Early tillering being most important trait for productivity, the influence of nitrogen on tillering was attempted. Highest tillering and advanced seed germination by one day was observed with overnight soaking of seeds in 1% urea solution when compared to the control and; the higher concentrations decreased the seed germination and plant growth. This investigation suggests the optimum LAI is 7.5 and optimum productive tillers are 190.9 m^{-2} to produce higher grain yield as compared to LAI of 6.58 in the recommended spacing of 22.5 cm x 10 cm. The early tiller production is possible through soaking the seed in 1 % urea solution overnight before sowing.

October 2018

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Y.A. NANJA REDDY
(Major Advisor)

ರಾಗಿಯ ಹೆಚ್ಚಿನ ಇಳುವರಿಗಾಗಿ ಪ್ರಶಸ್ತ ಎಲೆ ಪ್ರದೇಶ ಹಾಗೂ ಪ್ರಶಸ್ತ ಉತ್ಪಾದಕ ಕವಲುಗಳು ನಿರ್ಣಾಯಕತೆ

ಮುಜಾಹಿದ್ ಅಂಜುಂ

ಪ್ರಬಂಧ ಸಾರಾಂಶ

ರಾಗಿಯು ಒಂದು ಪ್ರಮುಖ ಮಳೆಯಾಶ್ರಿತ ಬೆಳೆಯಾಗಿದ್ದು, ಕಳಪೆ ಭೂಮಿಯಲ್ಲಿ ಬೆಳೆಯಲಾಗುತ್ತದೆ. ಈ ಬೆಳೆಯ ಇಳುವರಿಯು ತಟಸ್ಥ ಮಟ್ಟಕ್ಕೆ ತಲುಪಿದೆ. ಇದರ ಇಳುವರಿಯನ್ನು ಹೆಚ್ಚಿಸಲು ಕೈಗೊಳ್ಳಬೇಕಾದ ತಾಂತ್ರಿಕತೆಯಲ್ಲಿನ ಶಾರೀರಿಕ ವಿಧಾನ. ಇದರ ಸಲುವಾಗಿ, ಎರಡು ಪ್ರಯೋಗಗಳನ್ನು ವಲಯ ಕೃಷಿ ಸಂಶೋಧನಾ ಕೇಂದ್ರ, ಜಿ.ಕೆ.ವಿ.ಕೆ ಪ್ರಯೋಗ ತಾಕುಗಳಲ್ಲಿ ನಡೆಸಲಾಯಿತು. ಮೊದಲ ಪ್ರಯೋಗದಲ್ಲಿ ಮೂರು ರಾಗಿ ಜೀನೋಟೈಪ್‌ಗಳನ್ನು ಉಳಿಸಿ ವಿಭಿನ್ನ ಗಿಡ ಅಂತರಗಳೊಂದಿಗೆ ವಿಭಿನ್ನ ಎಲೆ ಪ್ರದೇಶಗಳನ್ನು ನೀಡುವಂತೆ ನಾಟಿ ಮಾಡಲಾಯಿತು. 15 × 10 ಸೆಂ.ಮೀ. ಅಂತರವೂ ಅತಿ ಹೆಚ್ಚು ಎಲೆಪ್ರದೇಶ (7.5)ನ ಜೊತೆಗೆ ಗರಿಷ್ಠ ಧಾನ್ಯ ಇಳುವರಿ (754.7 ಗ್ರಾಂ. ಪ್ರತಿ ಚದರ ಮೀಟರ್) ವಿಸ್ತೀರ್ಣಕ್ಕೆ ಹೆಚ್ಚಾಗುತ್ತಾ ಹೋಯಿತು. ಅದಾಗ್ಯೂ ಪ್ರತಿ ಚದರ ಮೀಟರ್‌ಗೆ 190.9 ಕವಲುಗಳು 15 × 10 ಸೆಂ.ಮೀ ನಾಟಿಯ ಅಂತರದಲ್ಲಿ ಅತಿ ಹೆಚ್ಚು ಇಳುವರಿಯನ್ನು ನೀಡಿತು. ಶೀಘ್ರ ಕವಲೊಡೆಯುವ ಸಾಮರ್ಥ್ಯವೂ ಇಳುವರಿಯನ್ನು ಹೆಚ್ಚಿಸುವ ಒಂದು ಪ್ರಮುಖ ಅಂಶವಾಗಿದೆ. ಆದುದರಿಂದ ಕವಲೊಡೆಯುವಿಕೆಯಲ್ಲಿ ಪೋಷಕಾಂಶದ ಪ್ರಭಾವವನ್ನು ತಿಳಿದುಕೊಳ್ಳಲು ಎರಡನೇ ಪ್ರಯೋಗವನ್ನು ನಡೆಸಲಾಯಿತು. ಇದರಲ್ಲಿ ಪ್ರಮುಖವಾಗಿ ಸಾರಜನಕದ ಪ್ರಭಾವದ ಬಗ್ಗೆ ಅರಿತುಕೊಳ್ಳಲು ನಡೆಸಲಾಯಿತು. ರಾತ್ರಿಯಿಡಿ ಶೇಕಡ 1 ರಷ್ಟು ಯೂರಿಯಾ ದ್ರಾವಣದಲ್ಲಿ ರಾಗಿ ಬೀಜಗಳನ್ನು ನೆನೆಸಿಡುವುದರಿಂದ ಹೆಚ್ಚಿನ ಕವಲು ಹಾಗೂ ಬೀಜ ಮೊಳಕೆಯೊಡೆಯುವಿಕೆಗೆ ಸಾಧ್ಯವಾಯಿತು. ಹೆಚ್ಚಾದ ಯೂರಿಯಾ ಪ್ರಮಾಣವು ಬೀಜ ಮೊಳಕೆಯೊಡೆಯುವಿಕೆ ಹಾಗೂ ಸಸ್ಯ ಬೆಳವಣಿಗೆಗೆ ಮಾರಕವಾಗಿ ಹೊರಹೊಮ್ಮಿತು. ಈ ತನಿಖೆಯಿಂದ ರಾಗಿಯ ಪ್ರಶಸ್ತ ಎಲೆ ಪ್ರದೇಶ ಸೂಚ್ಯಾಂಕ ಹಾಗೂ ಪ್ರಶಸ್ತ ಗರಿಷ್ಠ ಉತ್ಪಾದಕ ಕವಲುಗಳ ಸಂಖ್ಯೆಯನ್ನು ಕಂಡುಕೊಳ್ಳಲಾಯಿತು. ಪ್ರಶಸ್ತ ಎಲೆ ಪ್ರದೇಶ ಸೂಚ್ಯಾಂಕ 7.5 ಹಾಗೂ ಪ್ರಶಸ್ತ ಉತ್ಪಾದಕ ಕವಲುಗಳು 190.9 ಪ್ರತಿ ಚದರ ಮೀಟರ್ ಆಗಿ ಹೊರಹೊಮ್ಮಿತು. ಶೀಘ್ರ ಕವಲೊಡೆಯುವ ಸಾಮರ್ಥ್ಯವನ್ನು ಶೇಕಡ 1 ರಷ್ಟು ಯೂರಿಯಾ ದ್ರಾವಣದಲ್ಲಿ ಬೀಜವನ್ನು ರಾತ್ರಿಯಿಡಿ ನೆನೆಸಿಸುವುದರಿಂದ ಇದರ ಫಲಿತವನ್ನು ಕಂಡುಕೊಳ್ಳಬಹುದು.

ಅಕ್ಟೋಬರ್, 2018

ಬೆಳೆ ಶರೀರ ಕ್ರಿಯಾಶಾಸ್ತ್ರ ವಿಭಾಗ
ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾನಿಲಯ, ಗಾಂ.ಕೃ.ವಿ.ಕೇ., ಬೆಂಗಳೂರು–65

ವೈ. ಎ. ನಂಜಾರೆಡ್ಡಿ
ಪ್ರಧಾನ ಸಲಹೆಗಾರರು

Effect of planting densities on tillering, canopy cover and crop phenology in finger millet genotypes

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Introduction

Finger millet (*Eleusine coracana* (L.) Gaertn.) is a C_4 species (Ueno et al., 2016) belongs to family Poaceae. Finger millet is rich in quality protein and dietary fiber and minerals especially Ca and Fe (Devi *et al.*,2016). It is the most important small millet in the tropics (12% of total global millet area). The productivity of GPU-28 is 3.8 tonnes/ ha which is a shy tillering type. However in the recent years the productivity has reached the plateau (Anon, 2013) although the potential exists up to 10 tonnes of grain yield (ICRISAT). Further the research efforts have shown that the productive tillers up to 6-7 per hills found to increase the yield substantially (Anon,2017). One of the approaches is to enhance the tillering pattern and associated physiological traits would be the planting density. Therefore the present study was conducted to examine the tillering behavior, the canopy cover and crop phenology with varying levels of plant densities in comparison to 22.5 x 10 cms.

Objectives :

- To determine the effect of plant population on tillering.
- To decipher the effect of planting density on the flowering pattern.
- To assess the light insolation in the different planting densities.

Materials and Methods

1:Field Experiment

3 accessions of finger millet were sown in field with 7 treatments and 3 replications in randomized complete block design.

Field layout

20 Days after sowing

45 Days after sowing

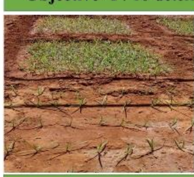
RCBD Design

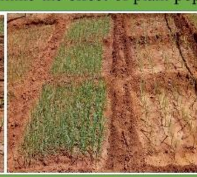
90 Days after sowing

60 Days after sowing

Physiological parameters measured at different stages of crop growth

Objective- I : To determine the effect of plant population on tillering





Objective-II :To assess the light insolation in the different planting densities.

Light intensity was measured by a row light quantum sensor/photometer (Li-cor)by keeping the meter in each row of the crop.

Objective – III : To decipher the effect of planting density on the flowering pattern.

Results

Table 1: Effect of planting densities on tillering pattern in finger millet genotypes at 28 DAT (45 DAS)

Treatments	Plants (No. m^{-2})	Tillers (No. hill^{-1})				Total tillers (No. m^{-2})
		GE-292	GPU-28	GE-199	Mean	
T_1 (30 x 15)	22.2	5.81	5.44	4.91	5.39	119.6
T_2 (30 x 10)	33.3	4.50	4.00	4.31	4.26	142.1
T_3 (22.5 x 10)	44.4	3.71	3.50	4.14	3.77	167.3
T_4 (15 x 10)	66.7	3.51	3.22	3.46	3.40	226.8
T_5 (10 x 10)	80.0	3.00	2.65	2.75	2.80	223.4
T_6 (10 x 7.5)	100.0	2.82	2.35	2.25	2.48	247.7
T_7 (10x 5)	200.0	2.15	2.18	1.83	2.05	410.4
Mean		3.64	3.32	3.38		
	Factors		C.D at 5%		SE(m) ±	
	Treatments		0.50		0.17	
	Genotypes		NS		0.11	
	Interaction		NS		0.30	
	CV (%)		15.2			

Table 2: Effect of planting densities on light interception in finger millet genotypes at flowering

Treatments	Plants (No. m^{-2})	Light interception (µ mol m^{-2})			
		GE-292	GPU-28	GE-199	Mean
T_1 (30 x 15)	22.2	146.5	44.3	163.9	118.2
T_2 (30 x 10)	33.3	115.6	53.4	175.4	114.8
T_3 (22.5 x 10)	44.4	60.9	18.1	69.6	49.5
T_4 (15 x 10)	66.7	42.3	31.8	62.4	45.5
T_5 (10 x 10)	80.0	35.2	19.0	48.4	34.2
T_6 (10 x 7.5)	100.0	34.7	22.4	42.0	33.0
T_7 (10x 5)	200.0	33.7	15.1	39.6	29.5
Mean		67.0	29.2	85.9	
	Factors	C.D at 5%		SE(m) ±	
	Treatments	8.98		3.1	
	Accessions	5.8		2.0	
	Interaction	15.5		5.4	
	CV (%)	15.4			

Table 3: Effect of planting densities on days to ear head emergence in finger millet genotypes

Treatments	Plants (No. m^{-2})	Days to ear head emergence			
		GE-292	GPU-28	GE-199	Mean
T_1 (30 x 15)	22.2	61.7	78.0	66.7	66.7
T_2 (30 x 10)	33.3	61.3	78.0	66.0	68.4
T_3 (22.5 x 10)	44.4	59.7	77.0	65.0	67.2
T_4 (15 x 10)	66.7	59.0	76.7	64.3	66.7
T_5 (10 x 10)	80.0	59.0	75.3	64.0	66.1
T_6 (10 x 7.5)	100.0	59.0	75.0	63.0	65.7
T_7 (10x 5)	200.0	59.0	75.0	63.0	65.7
Mean		59.8	76.4	64.6	
Factors		C.D at 5%		SE(m) ±	
Treatments		0.29		0.10	
Accessions		0.19		0.70	
Interaction		0.50		0.18	
CV (%)		0.45			

With increase in the planting density from 22.2 to 200 per m^2 have decreased the mean tiller number from 5.39 to 2.05 significantly. However the overall tiller number per m^2 was increased with increase in planting density reaching upto 410.4 per m^2 (Table 1). With increase in the planting density, there was a reduction in light interception from 118.2 to 29.5 µmol m^{-2}. The light intensity was least in GPU-28 in comparison to GE-292 and GE-199. With increase in the planting density, the days taken to ear emergence was reduced gradually. Maximum days to ear emergence was observed at 30 x 10 cm. compared to recommended spacing. Higher density planting resulted in early emergence (by 1.5 days). Among the genotypes GE-292 was short duration type with 60 days and GPU-28 belongs to mid duration groups with 76.4 days for ear emergence (Table 3).

Discussion

Planting density below the recommended leads to decreased tiller number. While increase in density increases the tiller number, shows the possibility to enhance tillers per unit area. Such increased density would increase the canopy cover resulting in decreased light insolation at ground. At higher planting densities, light being a limitation, plants grow taller and resulted in early flowering.

Summary

Tiller number per total hill is an important yield attributing trait, which can be further increased by increasing planting density higher than 22.5 x 10 cm.

Advisory committee

Chairperson : **Dr. Y.A. NANJA REDDY**
Member : **Dr. M.S.SHESHASHAYEE**
Member : **Dr. S. RAMESH**
Member : **Dr. H.M. JAYADEVA**

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I INTRODUCTION

Finger millet (*Eleusine coracana* (L.) Gaertn.) is an important millet crop grown extensively in India and Africa. In India, it is commonly called as ragi, nachli, nagli, mandua etc. It is a C_4 species with NAD-ME type of decarboxylation (Ueno *et al*., 2006) belongs to family Poaceae. It is a climate resilient crop with the ability of drought tolerance. Ragi is believed to have originated in Uganda, nearly 5000-6000 years back and then the domestication spread from western Uganda to the Ethiopian highlands. India is known as secondary origin. Finger millet is grown in more than 25 tropical countries and contributes to the 12% of global millet area.

Finger millet is the most nutritionally important crop with high content of grain calcium (0.38%), protein (6–13%), dietary fiber (18%), carbohydrates (65–75%), minerals (2.5–3.5%), phytates (0.48%), tannins (0.61%), phenolic compounds (0.3–3%) and trypsin inhibitory factors. It is recognized for its health benefits such as antitumerogenic, anti-diarrheal, antiulcer, anti-inflammatory, atherosclerogenic effects, antioxidant properties (Sripriya *et al*., 1996; Chethan and Malleshi, 2007; Devi *et al*., 2014).

Presently, in India it covers an area of 1.19 million hectares with a production of 1.98 million tons and productivity of 1661 kg ha^{-1}(Anon., 2015). The area under cultivation in India stands in sixth place after the wheat, rice, maize, sorghum and bajra (Chandra *et al*., 2016). Karnataka is the major finger millet producing state having 58% of its total production with an area of 6.3 lakh hectares accounting to 11.12 lakh tons of production with a productivity of 1759 kg ha^{-1} (Anon., 2013).

Breeding efforts have increased the grain yield of finger millet through the release of blast resistant high yielding varieties and following appropriate agronomical approaches. Among the yield attributes, productive tillers are the major trait in deciding the yielding ability of finger millet followed by ear weight and test weight in finger millet (Anon., 2017). The crop being cultivated as rain fed ecosystem, phenotypic plasticity of plants will adjust their morphology and phenology to varying environments and accordingly the productivity. One such trait having the plasticity is the productive tillers per unit land area, which depends on number of tillers and effective tillers/ hill and the plant density. It has been shown that the productive tillers alone contributes to 54 % yield followed by ear weight and test weight (Anon., 2017). The number of tillers per unit land area is determined by planting density, nutritional status of soil and moisture status of soil during crop growth period in addition to expression of genotypic character. In finger millet, variability exists for tiller number per hill (Anon., 2017). Determination of such appropriate trait is not studied extensively in popular variety, GPU-28 especially in terms of physiological attributes. This variety is shy tillering with 2 tillers/ hill reaching a maximum of productive tillers from 60 of 80 per square meter weighing each ear head approximately 6.0 g as per the recommend package of practices (Anon., 2015) and hence the potential yield could be raised to 48 q ha^{-1} under rainfed conditions. It has been reported that an increase in productive tillers increases the grain yield up to certain population density and then there will be a plateau or decreased yield of wheat (Richards, 2000). Therefore, any efforts to increase, an additional tiller per hill would be highly useful to enhance the potential yield of GPU-28 significantly. In this direction, studies on planting densities and physiological traits associated with it in differing plant densities would be highly relevant to achieve the yield potential of finger millet. This can be addressed though manipulating the planting density per unit land area under adequate irrigation and nutrition as per the package of practices. Such manipulations may lead to variation in leaf area. It was observed that the higher plant density increases the leaf area or leaf area index (Carberry *et al*., 1985). Hence, the optimum leaf area index required for tiller production and maximum grain yield in finger millet genotypes was proposed with varying plant densities.

Once the productive tillers per unit land area is optimized for higher grain yield, it would be required to enhance the tiller number per hill in a given genotype. Further, finger millet being a rain fed crop cultivated on marginal soils, rapid seed germination, early seedling establishment and uniform crop stand in an unpredicted rainfall pattern are vital for crop productivity. Seedlings with higher seedling vigour would tolerate early season moisture stress by spreading the canopy and minimal soil evaporation. This may allow the plants to take up water efficiently, convert that into biomass and leading to higher tillering. Finger millet being a C_4 species, photosynthetic rate would be relatively high, rapid leaf area accumulation at seedling stages would help in production of more number of tillers leading to more productivity (Berdahl *et al*., 1971). Among the major environmental factors that influence the seedling growth are variety, irrigation and nutrition especially the nitrogen. Therefore, it would be apt to look for the early effects of nitrogen on tillering behaviour which is a major yield determining factor in the finger millet. Further, the widely cultivated finger millet variety, GPU-28 being shy tillering in nature, the influence of nitrogen on tiller production would be highly useful.

With this background, experiments to "Assess the physiological basis of tiller production with differing plant densities in finger millet genotypes" have been formulated with the following objectives.

(a) To assess the physiological basis of tiller production in shy and profusely tillering genotypes with differing plant densities.

(b) To determine the optimum nutritional factor (Nitrogen) for maximizing the tiller production in Cv. GPU-28.

II REVIEW OF LITERATURE

Finger millet is an important staple food crop of southern India. The crop improvement programmes lead to development of suitable varieties and their adoption with appropriate agronomic practices have enhanced the grain yield and reached a plateau in the recent years (Swetha, 2011). The ruling variety, GPU-28 has shy tillering habit (2 to 2.5 tillers/ hill) with an optimum ear size of 6-7 g. Therefore, efforts to improve the tillering ability of GPU-28 would be relevant to increase the productivity and thus production. In this regard, the review and literature is presented as here under.

2.1 Physiological traits

2.1.1 Plant population

Opole (2012) reported that an increased population from 3.26 to 4.60 lakh ha^{-1} increased the grain yield significantly from 2321 to 2998 kg ha^{-1}, however further increase in plant population to 5.16 lakh ha^{-1} decreased grain yield to 2486 kg ha^{-1}.

Maobe *et al*. (2014) reported that the plant densities lower than 3,33,333 (30 cm × 10 cm) will reduce the grain yield significantly. Further an increase in plant population to 10 lakh ha^{-1} (100 hills m^{-2}) also reduced the panicle weight and grain weight significantly.

2.1.2 Days taken to flowering

Edmeades and Daynard (1979) have reported in maize that the days taken to anthesis did not vary significantly among the planting densities of 50000, 100000 and 150000 plants ha^{-1}. The mean days taken for flowering were 77.3, 76.9 and 77.7 days respectively.

Kanwar *et al*. (2000) conducted an experiment to know the effect of different population densities in onion and concluded that population density failed to register any effect on days to flowering and maturity.

In foxtail millet, Navale (2013) has shown significant differences for days to flowering in spacing of 30 cm × 30cm and 30 cm × 15cm. However, statistically the C.D value was only 0.5 days. Therefore, it suggests no marked differences in days to flowering with differing plant densities.

Anitha (2015) has reported that use of early aged seedlings for transplanting resulted in early flowering significantly. However, at given age of the seedling, the different spacing of 20 cm × 20 cm and; 30 cm × 30 cm did not influence the time taken to flowering.

2.1.3 Tiller number

Lafarge *et al.* (2002) have shown in grain sorghum that, with a decrease in plant density (16 to 2 plants m^{-2}), the tiller number increased from 3.2 to 5.2. Further, the productive tiller number was also increased by decreasing the planting density. This was due to the less production of non-fertile tillers in the lower planting densities with more spacing.

A Field experiment conducted under organic farming by Kalaraju *et al.* (2009) revealed that when the finger millet (Cv. GPU-28) was planted in square method, it produced higher number of tillers as compared to 22.5 cm × 10cm spacing.

Ogbodo *et al.* (2010) reported in rice that the wider spacing of 30 cm × 30 cm and also 20 cm × 20 cm have increased tillering linearly which was due to more photosynthetic efficiency and more feeding area and opportunity for better root growth provided by wider spacing compared to the lower spacing (higher plant densities).

Pandiselvi *et al.* (2010) shown that the number of tiller production is environmentally influenced. Early sowing has maintained relatively higher tiller number when compared to the delayed sowing and this was correlated to the grain yield. They observed that more number of tillers were registered under 30 cm × 30 cm when compared to 22.5 × 10 cm spacing. The tillering ability was attributed to the amount of more nutrients at wider spacing.

Michael *et al.* (2015) reported in Pearl millet that, with an increase in the intra row spacing from 15 to 30 cm, there was an increase in the number of tillers per plant from 4.3 to 5.4 tillers respectively. The trend was similar in the second year of experiment also.

A field trail conducted by Rajesh (2011) showed that the spacing of 15 cm × 15cm produced more number of tillers over the other spacings of 20 cm × 20 cm, 25 cm × 25cm, and 30 cm × 30cm in finger millet.

Shinggu and Gani (2012) reported that an increase in inter row spacing from 10 to 20 have decreased the grain yield in one season. In the other season it was the other way round.

Legwaila *et al*. (2014) showed in pearl millet that the wider plant spacing resulted in higher absolute number of tillers per plant as compared to the narrower plant spacing. Leaf area of pearl millet (landraces) was significantly higher in the wider plant spacing (35 × 75 cm) compared to the narrow spacing.

Maobe *et al.* (2014) shown that the number of tillers produced per unit land was increased as the planting density of finger millet was increased from 111,111 to 333,333 plants ha^{-1} and the similar trend for tillering was observed when the planting density was increased from 1,000,000 to 4,000,000 plants ha^{-1}.

Clerget *et al*. (2016) conducted an experiment on rice in IRRI unveiled that the plant distance can have a profound effect on average number of tillers in each plant. An average of 28 tillers grew out when plants were distant by 20 cm and; only 14.2 tillers when plants were space at only 6 cm apart. There was a significant and positive relation between the distance between plants in a row and tillering per unit land area. This result suggests that distance between the plants will control the emergence of tillers in rice and other tillering cereal crops.

Vijayalaxmi *et al*. (2016) unveiled that the transplanting of5 rice seedlings $hill^{-1}$ produced significantly more tillers m^{-2} at heading stage (429 m^{-2}) and was followed by 3 seedlings hill^{-1} and 1 seedling hill^{-1}. More number of tillers m^{-2} in high density planting might be due to more plants m^{-2}. However, in less density planting total tillers production per plant increased but increase in tillers production failed to meet total tillers m^{-2} due to reduction in initial plant population (Yadav *et al*., 2010).

Bhatta *et al.* (2017) have shown in finger millet that the tiller number was higher in 25 cm × 25 cm (System of Crop Intensification) in SRI method when 30 days aged seedlings transplanted.

Studies on planting densities in rice showed that the high density plots of 50 and 33.3 hills m^{-2} attained early maximum tillering stage than 16.7, 22.2 and 25 hills m^{-2}. High density plots took 37 days after transplanting for attaining maximum tillering, while low density plots attained at 46 days after transplanting. Higher number of tillers at maximum tillering stage was observed under plots treated with 50 hills m^{-2} (722 tillers) and 33.3 hills m^{-2} (511 tillers) as compared to 22.2 hills m$^{- 2}$ (393 tillers) and 16.7 hills m^{-2} (407 tillers) treatments. However, the reduction in number of tillers was higher in 50 hills m^{-2} and followed by 25 hills m^{-2} and 16.7 hills m^{-2}, respectively (Asmamaw, 2017).

Prakasha *et al.* (2018) reported that under the Guni method of finger millet cultivation, the spacing of 60 cm × 60 cm recorded significantly higher number of tillers (19.86 tillers hill^{-1}) in contrast to the normal recommended spacing of 30 cm × 10cm which recorded very low tiller number (4.67 tillers hill^{-1}). This was attributed to the large leaf area and good nutrient supply and overall plant growth.

2.1.4 Plant height

Mobasser *et al.* (2007) reported in rice that the plant height was highest at lower planting density (20 plants per m^2, 124 5 cm) and it was progressively decreased significantly to 113.5 cm with 120 plants per m^2.

Muranyi and Pepo (2013) found that with an increase in the planting density there was an increase in the plant height of maize while the row spacing did not increase plant height.

Maobe *et al.* (2014) reported no significant differences in plant height with variations in spacings.

Bhatta *et al.* (2017) reported that there was an increase in the plant height of finger millet when it was grown in square planting (25 cm × 25 cm) as compared to that of 20 cm x10 cm.

Prakasha *et al.* (2018) reported that finger millet planting with a wider spacing of 45 cm × 45 cm and 60 cm × 60 cm under Guni method of cultivation has resulted in significant increase in plant height at 30, 60, 90 days after sowing as compared to 22.5 cm × 10 cm.

2.1.5 Leaf area index

Berdahl *et al.* (1971) proposed that the large flag leaves favour the higher kernel weight, while smaller flag leaves favour the production of more culms in barley. The photosynthetic rates were similar between large and smaller leaves. LAI was greater in large leaved plant by 19% as compared to the small-leaf canopies in population-I and by 33% in population-II. Large-leaf lines exceeded small-leaf lines in yield and LAI by 70% and LAI respectively.

Edmeades and Daynard (1979) have shown in maize that, with increase in the plant densities from 50000 plants ha^{-1} to 150000 plants ha^{-1}, there was a decrease in the leaf area from $3890 cm^2$ to $3314 cm^2$.

Lunagaria and Shekh (2006) reported that in wheat LAI was higher in the narrow row spacing (15 cm) than in wider row spacing (22.5 cm). There was a clear cut difference in the trend of LAI. LAI was gradually increased up to the crop reached the anthesis stage and then reduced thereafter. These results establish a close correlation between LAI and radiation interception.

Waraduwage *et al*. (2015) showed that the relationship between the leaf area and the biomass in Arabidopsis was non-linear and variable depending on carbon partitioning.

The changes in the rosette size from small to large size are due to the small differences in partitioning to new leaf area and leaf thickness.

Prem *et al.* (2014) reported in rice the reduced spacing from 30 cm × 30cm to 25 cm × 25cm, increased the plant height, LAI and grain yield with no significant differences in harvest index. However, the tillers/ plant were decreased significantly and such yield increase was mainly attributed to the straw yield.

Dereje *et al.* (2016) have shown that at a given intra row spacing, with increase in the intra row spacing from 10 to 25, the LAI was decreased significantly from 4.2 to 1.7 respectively.

Asmamaw (2017) found in rice that the there was no significant differences in LAI due to variation in plant population density. The increase continued up to full heading stage in case of 16.7 and 33.3 hills m^{-2}, after which it started decreasing. The lowest LAI was witnessed at ripening stage of the crop. Leaf area index was highest at 50 hills m^{-2} and lowest was found at 22.2 hills m^{-2}. Higher population densities achieved higher leaf area index as compared to low population densities.

2.1.6 Light interception

Ali *et al.* (1984) have reported in pearl millet that in the narrow spacing, the light interception reached a maximum of 40% at 29 days after sowing and declined thereafter. While there was a significant increase in the medium spacing from 65-75% which was evident between 35 to 53 days after sowing. However, in the wider spacing, interception increased linearly from 17 DAS to a maximum of 50% at 51 DAS.

Watiki *et al*. (1993) reported in maize that the solar radiation interception at 21-60 crop stage was 371 and 474 MJ m^{-2} in low and high plant density respectively. These results infer that, with increase in the planting densities of maize, there was increase in the light interception. The maize plants in the high plant densities intercepted more radiation because of high LAI even after anthesis.

Lunagaria and Shekh (2006) reported in wheat the wider spacing facilitated more light penetration to the ground level when compared to narrow spacing. However, the narrow spacing intercepted higher PAR (0.92) fraction when compared to the wider spacing.

2.1.7 Specific leaf weight

Sashidhar (1987) studied in six germplasm lines that, a wide variation in SLW of ragi exist from 5.43 mg $cm^2$to 8.44 mg cm^2.

In finger millet variety, Hamsa and Indaf-7, Swetha (2011) reported a SLW of 4.39 and 6.64 respectively. There was a positive relationship between SLW and yield (Swetha, 2011).

2.1.8 Leaf yellowing at 20 DAF

Borrell *et al*. (2000) demonstrated that the stay-green type of sorghum hybrids produce 47% more post-anthesis biomass and yield as compared to their senescent counterparts under terminal water drought regime but not under adequate moisture conditions.

2.1.9 Photosynthetic rate

Dwyert and Tollenaar (1989) studied in finger millet that there was a decline in photosynthetic rate with an increasing plant density from 20000 to 130000 plants per ha^{-1} and the decline was genotype dependent.

Cox (1996) reported that 10-20% decrease in leaf CO_2 exchange rates with increasing plant densities (from 4.5 plants m^{-2} to 9 plants m^{-2}) and 40% lower LAI observed in low density was compensated by higher photosynthetic efficiency.

Franic *et al*. (2015) observed a significant decline in photosynthetic performance in high density population. With the increase in plant density available light in the canopy is reduced; plants exhibit photosynthetic acclimation to varying light intensity and have a reduced photosynthetic capacity in shaded environment.

2.1.10 Stomatal count and density

Kumara *et al*. (2013) have conducted an experiment on the effect of planting geometry and shade in Stevia. Stevia planted at 45 cm × 10 cm in an E–W direction remained on a par with 30 cm x15 cm in a N–S direction but, recorded significantly a higher lower stomata count than other spacing levels, which remained on a par with each other. Similarly, the upper stomata count was significantly higher at 30 cm x15 cm than at 45 cm × 10 cm in both the directions.

2.2 Yield and yield attributes

2.2.1 Grain yield

Reddy *et al*. (1974) reported an increased dry matter production with higher population in CR-652 variety of finger millet. Similarly, Puttaswamy and Krishnamurthy (1976) at Dharwad studied the pattern of dry matter accumulation and its distribution in two finger millet varieties under two levels of spacing (22.5 cm × 7.5 cm and 22.5 cm × 15.0 cm). The final dry matter accumulation per plant was more with widely spaced plants and the peak dry matter accumulation periods coincided with heading and grain filling stages.

Roy *et al.* (2001) reported that, a reduction in intra-row spacing from 10 to 6 cm have decrease the yield significantly keeping the same spacing between the rows (25cm). This signifies the intra-row competition.

Mobasser *et al*. (2007) found in rice, the varying plant densities from 20 to 120 plants per m^2 did not influence the filled spikelet, total spikelet number and 1000 grain weight. However, the productive tiller number drastically reduced from 12.5 (20 plants per m^2) to 6.9 (40 plants per m^2) and 4.8 (120 plants per m^2). In contrast, the panicle number was increased with increasing plant population from 20 to120 plants per m^2. The planting density of 120 plants per m^2 gave higher grain yield due to highest harvest index and panicle number rather than tiller number.

Sulthan and Kaleem (2007) studied in rice varieties ‘Pro Agro hybrid 6201’ had higher number of filled grains per panicle, length of panicle and test weight as well as seed yield over ‘PAC 801’ and ‘MPR 5629’ with the spacing of 20 × 20 cm over others. Similarly, in rice hybrid, Dineshkumar *et al.* (2008) studied the influence of plant density of 50 and 66 per m^2 for the three genotypes KHRS-21, Hemavathi and Intan.

Anitha (2015) reported that at any given age of seedling used for transplanting, altering the spacing from 30 cm x10 cm to 20 cm × 20 cm has increased the grain yield significantly due to increased straw weight and harvest index.

Nayak *et al.* (2003) have shown in rice that closer spacing of 20 cm x10 cm yielded significantly higher than that with spacing of 20 cm × 15 cm and they have also reported that planting of 2 seedlings per hill was beneficial for yield advantage of 8.2% over one seedling per hill.

Bitew and Asargew (2014) reported that planting finger millet from 20 cm to 30 cm row spacing increased grain yield by 14.8 %. This might be due to relative increment in yield components and reduction of lodging and blast diseases infestation. Highest gain yield in 30 cm as compared to narrow spacing (20 cm) could be also due to low nutrients, less light competition among the same plant in narrow spacing. The highest lodging and biomass at narrow row spacing might be due to low plant strength due to competition for nutrient at higher plant population. Further increase in row spacing from 30 cm to 40 cm and to 50 cm caused 5.3 % and 9.2 % yield reduction, respectively. These imply that there could be optimal row spacing, suggesting that increasing in row spacing could increase the grain yield initially, reach an optimum and further increases in row spacing would reduce the yield. This suggests that row spacing of 30 cm and closer from plant to plant spacing helps in better establishment of finger millet.

Maobe *et al*. (2014) reported that plant densities lower than 3,33,333 plants ha^{-1} (30 cm × 10 cm) will reduce the grain yield significantly. They have also shown that plant densities above 10 lakh ha^{-1} (100 hills/ m^2) significantly reduce the panicle weight and grain weight.

Dereje *et al.* (2016) have reported no marked differences in the grain yield with the intra row spacing varying from 10-15 cm in maize.

Clerget *et al*. (2016) reported that the mean grain yield of rice were significantly lower at 20cm plant distance (5.9 t ha^{-1}). This is mainly because of significantly lower panicle number (−14% and −20%) than at shorter distances, which could not be compensated for by the number of grains per panicle. The lower tiller density resulted in lower panicle density that makes this variation.

A significant interaction was observed between the inter-row planting densities on the grain yield of maize crop. In the standard inter-row spacing as compared to the narrow inter row spacing, the grain yield did not increase because of the higher planting density. On the other hand, the narrow inter row spacing showed a significant yield benefit when the plant population was increased from 7.5 to 10.5 plants m^{-2}.The highest yield was obtained in the narrow spacing with 12 plants m^{-2}. However, for this inter-row space system the plant density did not differ significantly in grain yield from 10.5 plants m^{-2}. However, the narrow inter-row spacing resulted in a significantly greater grain yield (+10.9%) than the standard inter-row spacing for the higher plant densities (Testa *et al*., 2016).

Vijayalaxmi *et al*. (2016) reported a higher grain yield (5817 kg ha^{-1}) in *kharif* rice from 5 seedlings $hill^{-1}$ and was significantly superior to 3 seedlings $hill^{-1}$ and one seedling $hill^{-1}$, in turn S1(one seedling $hill^{-1}$) recorded the lowest grain yield (5134 kg ha^{-1}). The increased grain yield of rice might be due to higher plant population, more leaf area index, more light interception and more number of effective tillers m^{-2} resulted in yield enhancement in 5 seedlings $hill^{-1}$ (Rasool *et al*., 2012). In addition to that, the improvement of yield contributing characters like number of effective tillers $hill^{-1}$, panicle length, spikelets $panicle^{-1}$ and test weight also contributed to yield enhancement (Islam *et al*., 2013).

2.2.2 Spikelet fertility

An experiment conducted in rice crop revealed that mean grain weight and rate of fertility were not affected by plant distance. Mean shoot biomass and grain yield at 6 cm and 10cm plant distances were close and larger than at 20 cm distance, though not significantly due to data variability (Clerget *et al*., 2016).

Asmamaw (2017) reported that the spikelet number per panicle was significantly different among density treatments. The spikelet number due to different densities ranges from 98 to 141 m^{-2}. Spikelet number per panicle increased as population density decreased from 50 to 16.7 hills. Highest mean spikelet number (141) was recorded in 16.7 hills m^{-2} followed by 22.2 hills m^{-2}, although both treatments were not significantly different. The least spikelet number (98) was obtained in 50 hills m^{-2} followed by 33.3 hills m^{-2} (107) and 25 hills m^{-2} (112). This is mainly due to proper nutrient availability and easy light penetration even to the lower leaves because of wider spacing. This is attributed to high dry matter accumulation per hill which further contributes an increase in spikelet number per panicle.

2.2.3 Mean ear head weight

An experiment conducted in maize crop unveiled that an average ear weight was decreased by 18% at the high plant density system. However, the key to the yield enhancement was obtained from the high plant population in modern hybrids, with higher number of kernels harvested per unit area, which was +26% and +23% respectively, comparing 7.5 and 10.5 plants ha^{-1}. For highly competitive conditions, which are typical of high plant populations, the final grain yield is linked more to the number of harvested kernels than to the kernel weight itself (Testa *et al*., 2016).

2.2.4 Test weight

Sultan and Kaleem (2007) revealed in rice 'Pro Agro hybrid 6201' a higher number of filled grains/panicle, length of panicle and test weight as well as seed yield over 'PAC 801' and 'MPR 5629' with the spacing of 20 cm ×20 cm over wider spacings.

Navale (2013) stated that the wider spacing of 30 cm × 15 cm recorded significantly higher test weight (2.59 g) over narrow spacing of 30 cm × 10 cm in ragi. This may be attributed to more number of leaves and tillers, which led to higher dry matter production and again it was positively correlated with panicle weight and finally resulted in higher yield.

Shahzad *et al*. (2015) reported that thousand grain weight decreased with an increasing planting density. Higher thousand grain weight of 253 g was recorded from lowest plant density of 65000 plants ha^{-1} which is at par with 80000 plants $ha^{-1}$with thousand grain weight of 250 g. Minimum thousand grain weight of 242 g was recorded from the highest planting density of 95000 plants ha^{-1}.

Vijayalaxmi *et al*. (2016) stated that either plant densities or age of seedlings did not exert any significant influence on test weight of *kharif* rice. However, studies conducted on planting densities of rice crop revealed significant differences in 1000 grain weight which was due to planting density variation. In almost all treatments, the average 1000-grain weight was similar indicating that the plant density has less influence on test weight. Asmamaw (2017) showed in rice that the there was no significant differences for 1000 seed weight for all the planting densities. The correlation graph also showed that there were no significant differences between the test weight and the paddy yield.

2.3 Effect of nitrogen levels on morpho-physiological characters

Positive effect of nitrogen on tillering has been observed (Mc Kenzie, 1998), because, nitrogen is associated with promoting cell division (Mc Adam *et al*., 1989). The nitrogen has mediatory role in tiller production through cytokinin production includes, more N absorption (Tomlinson and Connor, 2004). In other words, higher cytokinin / IAA ratio would be maintained (Chan *et al*., 1998).

Increase in nitrogen will increase the uptake of 'P' also and increases the plant growth. However, increase in nitrogen in the absence of 'P' showed no improvement in plant growth. The plant height of sorghum was increased up to 30 kg ha^{-1} and above which plant height was reduced (Ashiono *et al*., 2005).

Yadav *et al*. (2010) reported that the productive tillers and the grain yield was highest when the nitrogen dose was 40 kg ha^{-1}as compared to the lower doses and; increase in nitrogen up to 60 kg ha^{-1} was on par to that of 40 kg ha^{-1}. Therefore, 40 kg N ha^{-1} would be appropriate for potential yields under rain-fed situations.

Simakumari (2011) reported that finger millet genotypes respond positively to nitrogen levels and amongst 0, 20, 40 and 60 kg N/ha. Application of 40 kg N/ha resulted in significantly higher plant height, total tillers/plant, leaf area index (LAI) and dry matter accumulation (19.76 g/plant).

Opole (2012) reported that the increased nitrogen from 0 to 90 kg ha^{-1} did not enhance the plant height, SPAD reading, tiller number, biomass and grain yield significantly. Wherein the plots had lower nitrogen content, the absorption of applied nitrogen was low because of poor ‘P’ in soil, which is very much required for root growth primarily.

Decreased fertilizer especially N, reduces the growth parameters like plant height, number of leaves, number of tillers per hill, leaf area and dry matter and yield attributes and grain and straw yield of finger millet (Patil *et al*., 2015).

Jena *et al*. (2016) reported that, inclusion of 0.5 M nitrate in hydroponics on 20th day old finger millet resulted in more plant height as compared to zero or lower doses of nitrate in the medium. Further, such plants had higher leaf number per hill, higher leaf number, biomass and chlorophyll content. In addition, the nitrate reductase activity was more in plant tissue suggesting that, in hydroponics, 0.5 M nitrate could be optimum concentration for finger millet growth in hydroponics.

Fayisa *et al*. (2016) reported that the increased dose of fertilizer from 0 to 92 kg ha^{-1} did not increase the plant height significantly, although the grain yield was increased. The increased yield was due to an increased panicle length and straw yield. It suggests that in addition to nitrogen the phosphorus and potassium are also required for plant growth.

Reddy *et al*. (2018) reported that, the recommended dose of major nutrients (NPK) yields better with a significant reduction in plant height as compared to two sprays of urea (2 %), DAP (2 %), KNO_3 (2 %), Calcium nitrate (2%), 19:19:19 (2%) at 30 and 50 days after transplanting.

III MATERIAL AND METHODS

The field experiment was envisaged and conducted during the summer 2018 in order to decipher the optimum plant population in finger millet varieties to achieve optimum leaf area for higher productivity. Subsequently, a laboratory experiment was conducted during May to June, 2018 to study the influence of nutrition (nitrogen) for rapid tillering potential. The details of the experimental material and techniques used in these experiments are presented as here under.

3.1 EXPERIMENT I: To assess the physiological basis of tiller production with differing plant densities in finger millet genotypes

3.1.1 Experimental material

Three finger millet germplasm accessions (GE-292, GE-199 and GPU-28) were obtained from the All India Co-ordinated Small Millets Improvement Project (AICSMIP), G.K.V.K, Bengaluru and were used in the experiment.

3.1.2 Experimental site

Experiment was conducted at the Field Unit of Crop Physiology Department, Zonal Agricultural Research station, Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences, Bengaluru-65 (Plate1).

Design: Factorial randomized block design (Fig. 1)

Genotypes: GE-292, GE-199, GPU-28,

Replications: 3

Net Plot size: 1 m^2

Date of Sowing: 12/01/2018, (summer, 2018)

Situation: Field condition

Treatments: 7

Treatment No.	No. of plants m^{-2}	Treatments
T_1	22.2	30 × 15 cm
T_2	33.3	30 × 10 cm
T_3	44.4	22.5 × 10 cm
T_4	66.7	15 × 10 cm
T_5	100.0	10 × 10 cm
T_6	133.3	10 × 7.5 cm
T_7	200.0	10 × 5 cm

NORTH ↑								
REPLICATION I			**REPLICATION II**			**REPLICATION III**		
GE-292	**GPU-28**	**GE-199**	**GPU-28**	**GE-199**	**GE-292**	**GE-199**	**GE-292**	**GPU-28**
T_1	T_1	T_1	T_2	T_2	T_2	T_4	T_4	T_4
T_2	T_2	T_2	T_4	T_4	T_4	T_7	T_7	T_7
T_3	T_3	T_3	T_1	T_1	T_1	T_1	T_1	T_1
T_4	T_4	T_4	T_7	T_7	T_7	T_5	T_5	T_5
T_5	T_5	T_5	T_6	T_6	T_6	T_2	T_2	T_2
T_6	T_6	T_6	T_3	T_3	T_3	T_6	T_6	T_6
T_7	T_7	T_7	T_5	T_5	T_5	T_3	T_3	T_3

Fig. 1: Layout of field experiment

Plate 1. Experimental plot

Plate 2. Field view of the experiment

3.1.3 Soil properties

Table 1. The Physical and chemical properties of the soil in experimental site

particulars	value	Status
I. Soil physical properties		
Coarse sand (%)	16.5	International pipette method (Piper, 1966)
Fine sand (%)	43.4	
Silt (%)	17.8	
Clay (%)	21.2	
Soil type	Red sandy loam	
II. Soil chemical properties		
pH (1:2:5)	6.32	Neutral
EC 1:2:5) dSm^{-1}	0.12	Low
Available N (kg/ha)	326.0	Medium
Available P_2O_5(kg/ha)	42.6	High
Available K_2O (kg/ha)	189.4	Medium

3.1.4 Land Preparation

The plot was ploughed was thoroughly thrice with cultivator and harrowing was carried out. Clods were crushed with the help of the rotovator and levelling was done to lay out the experiment.

3.1.5 Manure

Manure in the form of FYM @ 7.5 t ha^{-1} was added to the soil 15 days prior to transplanting and was mixed well.

3.1.6 Fertilizer application

The fertilizer was applied to the soil as per the recommended dose of 50-40-25 kg ha^{-1} of NPK. NPK was applied in the form of urea, single super phosphate and muriate of potash respectively. Half of the recommended dose of nitrogen and full dose of phosphorous and potassium were given as basal dose at the time of sowing and the remaining 50% nitrogen in the form of urea was given as top dressing at 45 days after sowing (DAS).

3.1.7 Design and layout

The experiment was laid out in a factorial randomized block design with 7 treatments replicated three times in three varieties, GE-292, GE-199 and GPU-28 (Plate 2). Each variety was sown in one square meter net area in addition to border rows with three varieties.

3.1.8 Sowing

The finger millet genotypes were sown on 12/01/2018 in plastic crates (Plate 3) and were then transplanted to the main field at 17 DAS on 29/01/2018.

3.1.9 Plant protection

As a precautionary measure, Tricyclozole @ 2gm/ litre of water was sprayed to the crop twice at the time of flowering and 20 days after flowering. An insecticide spray of dimethoate was given to crop during flowering time to get rid of ragi aphids (Plate 4).

3.1.10 Spacing

Spacing was provided as per the treatments (30 × 15 cm to 10 × 5 cm) as detailed above.

3.1.11 Weeding

Weeding was carried out thrice within 30 days after transplanting. Manual weeding was undertaken.

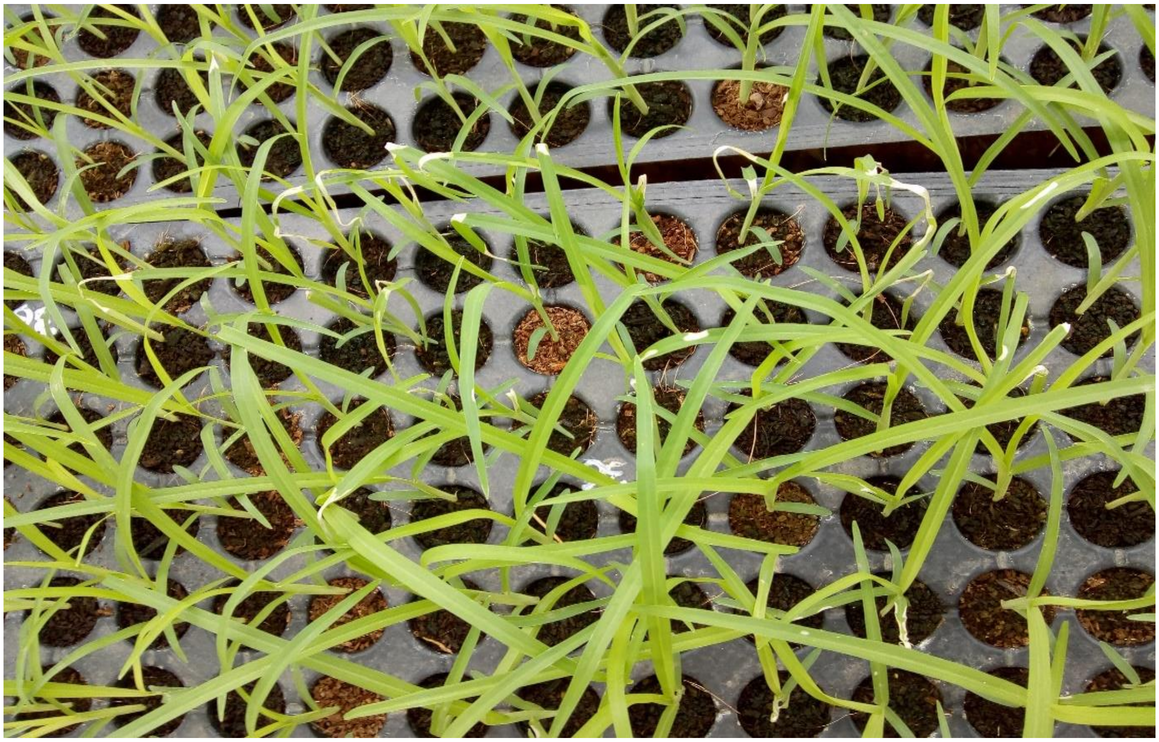

Plate 3. Seedlings raised in plastic crates

Plate 4. Plant protection measure

Plate 5: Lux meter

3.1.12 Irrigation

Optimal irrigation was provided to the crop on regular basis with the irrigation interval of 5-6 days.

3.1.13 Observations

Omitting the border plants, observations were recorded in 1 meter row length for parameters such as days to flowering, plant height, physiological traits, yield attributes and grain yield. Harvesting was carried out as and when the variety reached the maturity.

Physiological parameters

a) **Leaf area index:** The fully matured 3^{rd} leaf from randomly selected 5 tillers was selected and leaf length from the base to the tip of the leaf and the leaf width from the middle of the leaf were measured by using a measuring scale. The 3^{rd} leaf area was computed by multiplying the length × width × 0.75 (leaf shape factor) in three randomly selected plants in each replication. Then total leaf area of the plant was calculated by multiplying the computed leaf area × total number of leaves in the plant. Leaf area was measured at flowering and 20 days after flowering (Watson, 1947)

b) **Specific leaf weight (SLW) (mg. cm^{-2}):** In three randomly selected main tillers, 3^{rd} leaf length and width were measured to obtain the specific leaf area, the same leaf was oven dried to constant weight at 70°C till achieved constant weight. Using the leaf area (L × B was multiplied with leaf correction factor 0.75**)** and leaf dry weight, the SLW was computed (Pearce *et al*, 1968) as,

$$SLW = \text{Leaf dry weight (mg)} / \text{Leaf area } (cm^2)$$

c) **Light interception (μ mol m^{-2}):** The total amount of light insolation at ground level was recorded by placing the light quantum sensor (Li-Cor) in the rows. The light interception was measured at 26 DAS and at flowering.

d) **Thermal imaging:** Thermal imaging technique can be employed as one of the best strategies to measure the canopy temperature. The thermal imaging was done with the help of the thermal imager (Fluke). The images of each plot were captured with the help of the thermal imager on the IR mode and were further processed to arrive at the canopy temperature values. The thermal imaging was done at 26 DAS and at flowering.

e) **Leaf yellowing at 20 days after anthesis:** The number of leaves turned yellow from the base of the tiller in a given hill was counted after 20 days after anthesis. In each plot three random plants were counted and recorded.

f) **Photosynthetic rate at flowering:** The photosynthetic rate, stomatal conductance and transpiration were measured on 3^{rd} leaf from the apex using Infrared Gas analyser (IRGA) (Cyrus). The gas exchange parameters were measured during the 9.00- 11.00 AM on bright sunny days, wherein the Photosynthetically Active Radiations (PAR) was fixed at 1500 µM $m^{-2}s^{-1}$.

g) **Stomatal frequency:** The leaf samples were collected from each plot and were labelled and brought to the laboratory by keeping the leaf samples in a beaker containing water. Later the samples were smeared with the xylene paste, once dried, it was sticked with transparent cellophane tape on a glass slide. The slide was observed under 40X resolution of microscope (Lawrence & Mayo) and the frequency of stomata occurring under the microscope was computed as number per microscopic field.

Yield parameters

a) **Days to 50 % flowering (days):** Crop stage when more than 50 % of plants attained flowering in the plot were called as days to 50 % flowering.

b) **Plant height:** Using a measuring scale, the height of the plant was recorded at 3 different intervals (40 DAT, flowering and at harvest) by measuring from the base of the main tiller to the tip of the truly formed leaf at 40 DAT and; to tip of the ear head in five randomly selected main tillers and expressed in cm.

c) **Tiller number:** The total number of tillers produced by the plant was counted by counting all the tillers produced in the plot at 38 DAS and 45 DAS and calculated per hill and also per one square meter area.

d) **Productive tillers and number of ears:** Total number of tillers bearing ear head was called as productive tiller. The productive tillers and also number of ears were counted for each plot and the number of productive tillers and ear head number per one square meter area was computed and expressed as No.m^{-2}.

e) **Ear weight (g. m^{-2}):** After counting the productive tillers and ear number, the ears were separated and dried in cloth bags under sunlight, weighed and termed as total ear weight and was expressed as g.$^{m-2}$.

f) **Mean ear weight (g):** It was calculated by dividing the total ear head weight with the number of ear heads from one square meter area which was expressed as g.

g) **Grain yield (g. m^{-2}):** Once the total ear weight was recorded, it was threshed, cleaned and grain weight was recorded, and computed to one square meter area and expressed as g. m^{-2}.

h) **Test weight (g/ 1000 grain):** 1000 seeds were counted with the help of seed counter which were weighed and expressed in g.

i) **Total dry matter (g. m^{-2}):** The fresh straw obtained from the plot was weighed and a sample was taken and dried using the hot air oven (70^{o}C) to a constant weight (the sample dry weight was used to convert the total fresh weight to dry weight) and this was added to total ear weight to arrive at total dry matter (TDM) and expressed as g. m^{-2}.

j) **Harvest index (HI):** It is the ratio of seed yield to the total dry matter and expressed as ratio.

k) Spikelet fertility: It is the measure of the viable spikelets present inside the florets. The spikelet fertility was calculated by cutting 2cm long finger length and carefully dissecting the florets and spikelets. The fertility was then calculated by the number of filled grains and total number of spikelets and florets.

g) Statistical analysis: The data was analysed in factorial randomized block design using two factor statistical package OPSTAT developed by CCSHAU. The coefficient of variation was calculated as stated below (Sheoran *et al.*, 1998).

$$\text{C.V.}(\%) = \frac{\sqrt{\text{Error mean sum of squares}}}{\text{Grand Mean}}$$

3.2 EXPERIMENT II: To determine the optimum nutritional factor (nitrogen) for maximizing the tiller production in Cv. GPU-28.

The ruling variety GPU-28 was used to determine the optimum nutritional factor the nitrogen for tiller production. The experiment was conducted at the glass house facility. Department of Crop Physiology, University of Agricultural Sciences, Bengaluru during May- 2018.

3.2.1 Experimental design

The experiment was conducted in glass house condition in completely randomized design (CRD) comprised of nine treatments in three replications.

Treatment No.	Treatments
1	Recommended NPK (Control)
2	Twice the N & Rec. P & K
3	Thrice the N + Rec. P & K
4	Seed Treatment (1 % urea)
5	Seed Treatment (2 % urea)
6	Seed Treatment (3 % urea)

3.2.2 Experimental protocol

Seeds were initially soaked in water (for T_1 to T_6) and in different concentrations of urea (1%, 2% & 3%) overnight (for T_7 to T_9). The pre-soaked seeds were sown in the plastic water cups filled with quartz sand, these cups were placed in plastic tray fitted with thermocol sheet and half filled with the Hoagland's nutrient solution. The thermo cool sheets were cut into the desired size looking into the size of the glass and were kept on the plastic trays containing the nutrient solution so as to immerse the glasses into the nutrient solution. The plastic trays were half filled with the Hoagland nutrient media. The glasses were pricked at the bottom with small pin so as facilitate the movement of solution inside the glasses (Plate 6 and 7).

Table 2. Composition of the Hoagland's nutrient media

Sl. No.	Chemical	Conc.	Stock Soln. (g/ L)	Final Soln. (mL/L)	Complete	(-N)	(2N)	(3N)
1	KNO_3	2M	202	2.5	2.5	X	X	X
2	$Ca (NO_3)$	1M	236	2.5	2.5	X	X	X
3	NH_4NO_3	1M	80	1	1	X	7	10.5
4	KH_2PO_4	1M	136	0.5	0.5	0.5	0.5	0.5
5	$MgSO_4$	2M	493	1	1	1	1	1
6	H_3BO_3		2.86	1	1	1	1	1
7	$MnCl_2$		1.81	1	1	1	1	1
8	$ZnSO_4$		0.22	1	1	1	1	1
9	$CuSO_4$		0.05	1	1	1	1	1
10	$H_2MoO_4/NaMoO_4$		0.09/0.1	1	1	1	1	1
11	Fe Chelate (Sprint138)		15	1.5	1.5	1.5	1.5	1.5
	Additional							
12	KCl	1M				5	5	2.5
13	$CaCl_2$	1M				2.5	2.5	2.5
	Total			14	14	15.5	22.5	23.5

Hoagland and Arnon, 1937 (modified)

Observations

a) **Days to seed germination (days):** The time taken by the seeds to germinate in terms of days was recorded for each treatment.

b) **Days to initiation of tillering:** The time taken by the plants for initiation of tiller production in each treatment was recorded.

c) **Plant height (cm):** Plant height was recorded from the base of the main tiller to the top of the axis of fully emerged leaf in each replication. The plant height was recorded at the initiation of tillering and at 30 DAS which is expressed in cm.

d) **Number of tillers/ hill with time:** Tillers were counted on 30 DAS/ hill.

e) **Leaf number on main tiller:** The total leaf number on main tiller was recorded on the 30^{th} DAS.

f) **Basal stem girth (cm):** The basal stem girth of the main tiller was recorded on harvest of the plant which was expressed in cm. Basal stem girth was measured by electronic Vernier callipers.

g) **1^{st} internode length of main tiller:** The length of the first internode of the main tiller was measured from the base of the main tiller to the nodal end of the 1^{st} internode with the help of the measuring scale during the harvest of the plants on 30 DAS.

h) **Leaf area (cm^2):** All the fully matured leaves were measured for length and width in a plant and multiplied with 0.75 to arrive leaf area per plant.

i) **Biomass of root and stem:** The total biomass of the root and stem was computed after the harvest of the plants (30 DAS) in each treatment and was expressed in g $plant^{-1}$.

IV RESULTS AND DISCUSSION

Owing to the tremendous contributions from crop improvement programmes, India has attained self -sufficiency in terms of calories. However, nutrients and other quality aspects have been gradually declining. This trend is perhaps due to an increased proportion of consumption of cereals that are intrinsically poor in nutrients. Cereals like rice has also been the major culprit through its consumption of huge volumes of water. Thus, there has been increased emphasis on adopting alternate food crops that have the potential to mitigate the malnutrition especially in India.

Finger millet is one such crop that has huge potentials for providing nutritional security especially in dry rainfed areas. However, yield of finger millet has remained poor over the years. Lack of intervention of research can be considered as one of the major factors for the low production of Ragi. However, this crop is predominantly grown under rainfed conditions where water is one of the major factors constraining productivity. Though a C_4 species, Ragi is grown under rainfed conditions and on marginal soils, which result in severe reduction in productivity.

Among the several factors, the shy tillering ability of finger millet resulting in low level of productive tillers is regarded as the most important constraint for achieving the potential productivity. This investigation aimed to enhance productive tillers per unit area by manipulating plant density.

4.1.1 Days to flowering

It is a well-established fact that the crop duration has positive relationship with the grain yield (Krishnasastry *et al*., 1982). Density of planting did not any influence on days to flowering. However, significant variation between genotypes were observed. The medium duration genotype GPU-28 had 7-8 days for flowering as compared to medium duration and short duration genotypes GE-199 and GE-292 (Table 3). Similarly, no significant differences were between the plant densities for flowering has been reported by Edmeades and Daynard (1979), Navale (2013) and Anitha (2015). Therefore, the plant densities may not influence the duration of crop to a considerable extent.

Table 3: Effect of planting densities on days to 50% flowering in finger millet genotypes

Treatments (cm)	Plants (No. m^{-2})	Days to 50% flowering			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	64.0	68.0	80.0	**70.7**
T_2 (30 × 10)	33.3	61.7	67.0	79.0	**69.4**
T_3 (22.5 × 10)	44.4	61.0	67.0	78.7	**68.9**
T_4 (15 × 10)	66.7	61.0	66.3	77.7	**68.3**
T_5 (10 × 10)	100.0	61.0	66.0	77.0	**60.0**
T_6 (10 × 7.5)	133.3	61.0	66.0	77.0	**60.0**
T_7 (10 × 5)	200.0	61.0	66.0	77.0	**60.0**
Mean		**61.0**	**66.7**	**78.0**	

Factors	**SE(m) ±**	**C.D at 5%**
Treatments	0.091	0.26
Accessions	0.05	0.17
Interaction	0.16	0.45
CV (%): 0.40		

4.1.2 Plant height

Plant height is one of the yield attributing factors as it influences the biomass production (Reddy *et al*., 2013). There were no significant differences between plant densities from 30 × 15 cm to 10 × 5 cm (Table 4). However significant differences were observed in plant height at the time of flowering (Table 3). In overall, considering plant height at growth stages (24 DAT, flowering and maturity), no prominent effect on plant height was observed (Table 4,5 and 6). However, the plant height between the genotypes differed significantly and relatively GPU-28 had taller plant height at any given growth stage (Table 4, 5 and 6). However, in the present experiment inconsistent trend in plant height with the plant densities is observed. Increased plant density is expected to create competition among plants for light. This would stimulate plants to grow taller (Anitha, 2015). However, this trend of increasing plant height was not noticed at high density planting. Hence, it would be possible to enhance productive tiller number over specific land area.

4.1.3 Tillering

At 21 DAT, significant differences between the genotypes were observed for tillering behaviour. There was an increase in the mean tiller number per plant anda significant increase in the total tillers/ m^2. Shy tillering type GPU-28 has shown significantly low tiller number per plant (2.58) (Table 7).

Even at 28 DAT, by the mean tiller number per plant have been increased (Table 8). Where in the tiller number was reduced from 5.39 to 2.05 with increase in the plant density. The genotypes did not differ significantly for mean tiller number as well as interaction whether it is profuse or shy tillering habit. However, when the plant density is increased there is an increase in the total tiller numbers. Finger millet plants do not compensate for low plant density increasing tiller production (Maobe *et al*., 2014). Our results showed similar trend as that of Kalaraju *et al*. (2009), Bhatta *et al*. (2017) and Prakasha *et al*. (2018).

Table 4: Effect of planting densities on plant height at 24 DAT in finger millet genotypes

Treatments (cm)	Plants (No. m^{-2})	Plant height (cm)			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	61.57	56.30	57.62	**58.50**
T_2 (30 × 10)	33.3	59.32	56.89	65.32	**60.51**
T_3 (22.5 × 10)	44.4	59.39	59.28	67.06	**61.91**
T_4 (15 × 10)	66.7	52.85	56.45	54.72	**54.67**
T_5 (10 × 10)	100.0	65.24	58.99	56.27	**60.16**
T_6 (10 × 7.5)	133.3	60.31	56.37	62.43	**59.70**
T_7 (10 × 5)	200.0	55.78	62.83	60.44	**59.68**
Mean		**59.21**	**58.16**	**60.55**	

Factors	**SE(m) ±**	**C.D at 5%**
Treatments	1.68	NS
Genotypes	1.10	NS
Interaction	2.91	NS
CV (%): 8.55		

Table 5: Effect of planting densities on plant height at flowering in finger millet genotypes

Treatments (cm)	Plants (No. m^{-2})	Plant height (cm)			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	112.86	105.26	126.03	**114.72**
T_2 (30 × 10)	33.3	109.90	110.10	121.16	**113.72**
T_3 (22.5 × 10)	44.4	119.69	112.70	133.46	**121.95**
T_4 (15 × 10)	66.7	116.45	109.84	119.43	**115.24**
T_5 (10 × 10)	100.0	113.96	114.20	121.25	**116.47**
T_6 (10 × 7.5)	133.3	111.49	107.90	126.30	**115.23**
T_7 (10 × 5)	200.0	117.13	108.15	121.12	**115.47**
Mean		**114.50**	**109.74**	**124.11**	

Factors	**SE(m) ±**	**C.D at 5%**
Treatments	1.74	5.01
Genotypes	1.14	3.28
Interaction	3.02	NS
CV (%): 4.51		

Table 6: Effect of planting densities on plant height at harvest in finger millet genotypes

Treatments (cm)	Plants (No. m^{-2})	Plant height (cm)			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	121.40	106.00	119.00	**115.46**
T_2 (30 × 10)	33.3	117.26	108.83	114.80	**113.63**
T_3 (22.5 × 10)	44.4	128.06	113.50	116.80	**119.45**
T_4 (15 × 10)	66.7	119.40	109.56	121.60	**116.85**
T_5 (10 × 10)	100.0	119.66	105.06	122.80	**115.84**
T_6 (10 × 7.5)	133.3	124.26	109.93	130.06	**121.42**
T_7 (10 × 5)	200.0	114.86	102.53	124.73	**114.04**
Mean		**120.70**	**107.91**	**121.40**	

Factors	SE(m) ±	C.D at 5%
Treatments	2.81	NS
Genotypes	1.84	5.28
Interaction	4.87	NS
CV (%): 7.21		

Table 7: Effect of planting densities on tillering behavior in finger millet genotypes at 21 DAT (38 DAS)

Treatments (cm)	Plants (No. m^{-2})	Tillers (No. $hill^{-1}$)			Mean	Total tillers (No. m^{-2})
		GE-292	GE-199	GPU-28		
T_1 (30 × 15)	22.2	3.71	4.24	3.35	3.77	**83.7**
T_2 (30 × 10)	33.3	3.16	4.04	2.86	3.35	**111.7**
T_3 (22.5 × 10)	44.4	3.14	3.74	2.64	3.17	**140.9**
T_4 (15 × 10)	66.7	3.06	3.39	3.02	3.16	**210.6**
T_5 (10 × 10)	100.0	2.75	2.35	1.96	2.3	**188.2**
T_6 (10 × 7.5)	133.3	2.62	2.25	2.16	2.3	**234.1**
T_7 (10 × 5)	200.0	2.08	1.66	2.05	1.93	**385.4**
Mean		**2.94**	**3.09**	**2.58**		

	Factors	C.D at 5%	SE(m) ±
	Treatments	0.42	0.15
	Genotypes	0.27	0.10
	Interaction	NS	0.25
CV (%): 15.22			

Table 8: Effect of planting densities on tillering behavior in finger millet genotypes at 28 DAT (45 DAS)

Treatments (cm)	Plants (No. m^{-2})	Tillers (No. $hill^{-1}$)			Mean	Total tillers
		GE-292	GE-199	GPU-28		
T_1 (30 × 15)	22.2	5.81	4.91	5.44	**5.39**	119.6
T_2 (30 × 10)	33.3	4.50	4.31	4.00	**4.26**	142.1
T_3 (22.5 × 10)	44.4	3.71	4.14	3.50	**3.77**	167.3
T_4 (15 × 10)	66.7	3.51	3.46	3.22	**3.40**	226.8
T_5 (10 × 10)	100.0	3.00	2.75	2.65	**2.80**	223.4
T_6 (10 × 7.5)	133.3	2.82	2.25	2.35	**2.48**	247.7
T_7 (10 × 5)	200.0	2.15	1.83	2.18	**2.05**	410.4
Mean		**3.64**	**3.38**	**3.32**		
	Factors		**C.D at 5%**		**SE(m) ±**	
	Treatments		0.50		0.17	
	Genotypes		NS		0.11	
	Interaction		NS		0.30	
CV (%): 15.22						

4.1.4 Leaf area index (LAI)

Leaf area index is a number of time as canopy occupies the ground area, which ranged from 4.65 in 30 × 15 cm to 7.19 in 10 × 5cm (Table 9). The Leaf area index was increased significantly from 30 × 15 cm to 15 × 10 cm. Further, increase in plant density up to 10 × 5 did not increase the leaf area index significantly. Similar results have been reported by Lunagaria and Shekh (2006). However, Asmamaw (2017) reported no significant differences up to 33.3 hills per m^2. Our results show that possibly, the planting density may be increased to 66.6 hills per m^2 (15 × 10 cm) to achieve highest canopy cover to intercept higher solar radiation so as to result in higher productivity.

4.1.5 Light interception

Solar radiation interception by the chlorophyll pigment is known to play a role in the light reactions of photosynthesis and direct relationship between light interception and the canopy photosynthesis has been reported (Liu *et al*., 2011). In the present study, with increase in the plant density, light penetration to the ground level has been decreased significantly both at early growth stage (7 DAT) and at flowering (Table 10 and 11). This means that more light was intercepted at higher plant densities due to large Leaf area index. Similar results of increased light interception with increased plant densities have been reported in different crops by Watiki *et al*. (1993) and Lunagaria and Shekh (2006). Further the data on light penetration on early stages (7DAT) decipher that early growth of finger millet is rapid as light penetration is very low even at wider spacing in all the genotypes tested. The light penetration to ground level decreased at flowering where maximum canopy development is expected. The light intensity above the canopy was around 1400 µ mol m^2 s^{-1}, considering this even at the wider spacing, the light interception was nearly 85%. Hence, the light interception during the grand growth phase or flowering may not be a limitation in finger millet with present recommendation of 22.5 × 10 cm spacing. Therefore, increasing or decreasing the plant population from the existing package of 22.5 × 10 cm might not have a significant role on light penetration.

Table 9. Effect of plant spacing on leaf area index at flowering in finger millet genotypes

Spacing	Hills m^{-2}	Leaf area index			Mean
Treatments (cm)		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	4.61	4.17	5.18	**4.65**
T_2 (30 × 10)	33.3	5.65	4.25	5.80	**5.23**
T_3 (22.5 × 10)	44.4	5.75	6.04	7.96	**6.58**
T_4 (15 × 10)	66.7	9.27	6.88	6.34	**7.50**
T_5 (10 × 10)	100	8.64	7.25	5.67	**7.19**
T_6 (10 × 7.5)	133.3	8.82	5.85	6.18	**6.95**
T_7 (10 × 5)	200	8.81	6.37	6.41	**7.20**
Mean		**7.37**	**5.83**	**6.22**	
	Factors	**SEm +**		**CD @ 5 %**	
	Spacing	0.20		0.58	
	Varieties	0.13		0.38	
	S × V	0.35		1.01	
C.V. (%): 9.4					

Table 10: Effect of planting densities on light penetration at ground level in finger millet genotypes at 7 DAT (24 DAS)

Treatments (cm)	Plants (No. m^{-2})	Light penetration (μ mol m^{-2} s^{-1})			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	210.2	224.0	296.2	**243.4**
T_2 (30 × 10)	33.3	173.9	194.0	289.6	**219.2**
T_3 (22.5 × 10)	44.4	125.9	95.5	171.2	**130.9**
T_4 (15 × 10)	66.7	71.1	80.2	76.7	**76.0**
T_5 (10 × 10)	100.0	80.8	104.5	91.8	**92.4**
T_6 (10 × 7.5)	133.3	67.3	73.2	83.2	**74.6**
T_7 (10 × 5)	200.0	48.2	52.9	50.0	**50.4**
Mean		**111.1**	**117.7**	**151.2**	
	Factors	**C.D at 5%**		**SE(m) ±**	
	Treatments	47.8		16.7	
	Accessions	31.3		10.9	
	Interaction	NS		28.8	
CV (%): 39.44					

Table 11: Effect of planting densities on light penetration at ground level in finger millet genotypes at flowering

Treatments (cm)	Plants (No. m^{-2})	Light penetration (μ mol $m^{-2}s^{-1}$)			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	146.5	163.9	44.3	**118.2**
T_2 (30 × 10)	33.3	115.6	175.4	53.4	**114.8**
T_3 (22.5 × 10)	44.4	60.9	69.6	18.1	**49.5**
T_4 (15 × 10)	66.7	42.3	62.4	31.8	**45.5**
T_5 (10 × 10)	100.0	35.2	48.4	19.0	**34.2**
T_6 (10 × 7.5)	133.3	34.7	42.0	22.4	**33.0**
T_7 (10 × 5)	200.0	33.7	39.6	15.1	**29.5**
Mean		**67.0**	**85.9**	**29.2**	
	Factors	**C.D at 5%**		**SE(m) ±**	
	Treatments	8.98		3.1	
	Accessions	5.8		2.0	
	Interaction	15.5		5.4	
CV (%): 15.48					

4.1.6 Canopy temperature

Canopy temperature is the ability to cool the canopy by the process of transpiration i.e maintenance of cooler canopy will have higher transpiration rate and expected to fix more carbon. In the present study, spacing (plant densities) did not reflect in significant differences in canopy temperature (Table 12). The crop was raised under sufficient irrigation levels, this could be the reason for more differences between the treatments for canopy temperature. It reflects that under adequate moisture conditions canopy temperature measurement may not have a relevance with respect to the planting densities. However, genotypic differences exist (Table 12) due to inherent genetic makeup.

4.1.7 Specific leaf weight

Specific leaf weight, depicts the thickness of mesophyll layer, which is relevant in determining the water use efficiency. The specific leaf weight may have more relevance under rainfed situations. In the present study, decreasing the plant densities significantly decreased the specific leaf weight (Table 13). Such reduction is expected as the plant tries to produce larger area than thickness for interception of light under high plant densities. Our results show that increase in plant density from 22.5 × 10 cm to 15 × 10 cm increased the specific leaf weight markedly. Hence, 15 cm × 10 cm may be optimum to achieve relatively higher SLW with higher number of hills m^{-2}.

4.1.8 Stay greenness

Stay greenness is one of the good indicators for current canopy photosynthesis under adequate moisture conditions (Lopes and Reynolds, 2012). We measured yellowing of older leaves in present study, wherein increased plant density increased the number of leaves turning chlorotic. However, the lower leaves being small in nature, two leaves become chlorotic (Table 14) may not be a major constraint under adequate moisture conditions with given space. Therefore, the spacing under the normal conditions did not have a major role in maintaining the green leaves.

Table 12: Effect of planting densities on canopy temperature in finger millet genotypes at flowering

Treatments (cm)	Plants (No. m^{-2})	Canopy temperature (°C)			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	28.9	26.6	27.0	**27.5**
T_2 (30 × 10)	33.3	29.0	28.1	27.6	**28.2**
T_3 (22.5 × 10)	44.4	28.1	27.2	27.7	**27.6**
T_4 (15 × 10)	66.7	27.0	27.4	27.8	**27.4**
T_5 (10 × 10)	100.0	28.4	28.4	27.9	**28.3**
T_6 (10 × 7.5)	133.3	28.2	27.6	28.1	**27.9**
T_7 (10 × 5)	200.0	28.4	28.1	27.1	**27.9**
Mean		**28.3**	**27.6**	**27.6**	
	Factors	**SE(m) ±**		**C.D at 5%**	
	Treatments	0.32		NS	
	Genotypes	0.21		0.60	
	Interaction	0.56		NS	
CV (%): 3.48					

Table 13. Effect of plant spacing on specific leaf weight at flowering in finger millet genotypes

Spacing Treatments (cm)	Hills m^{-2}	Specific leaf weight ($mg\ cm^{-2}$) GE-292	GE-199	GPU-28	Mean
T_1 (30 × 15)	22.2	4.97	6.86	6.15	**5.98**
T_2 (30 × 10)	33.3	5.19	6.56	6.96	**6.24**
T_3 (22.5 × 10)	44.4	5.10	5.92	5.50	**5.51**
T_4 (15 × 10)	66.7	4.77	5.85	7.06	**5.90**
T_5 (10 × 10)	100	4.16	6.37	7.64	**6.06**
T_6 (10 × 7.5)	133.3	4.29	6.21	7.70	**6.070**
T_7 (10 × 5)	200	3.75	5.70	6.20	**5.22**
Mean		**4.66**	**6.21**	**6.74**	
	Factors	**SEm +**		**CD @ 5 %**	
	Spacing	0.12		0.35	
	Varieties	0.07		0.23	
	S × V	0.21		0.60	
C.V. (%): 6.2					

Table 14. Effect of plant spacing on Number of chlorotic leaves at 20 days after flowering in finger millet genotypes

Treatments (cm)	Plants (No. m^{-2})	Leaf yellowing at 20 DAF			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	0.11	0.11	0.00	**0.07**
T_2 (30 × 10)	33.3	0.00	0.00	0.00	**0.00**
T_3 (22.5 × 10)	44.4	0.33	0.11	0.00	**0.15**
T_4 (15 × 10)	66.7	0.56	0.44	0.22	**0.41**
T_5 (10 × 10)	100.0	1.33	1.22	0.89	**1.15**
T_6 (10 × 7.5)	133.3	1.89	1.33	1.22	**1.48**
T_7 (10 × 5)	200.0	2.56	1.89	1.56	**2.00**
Mean		**0.97**	**0.73**	**0.56**	
	Factors	**SE(m) ±**		**C.D at 5%**	
	Treatments	0.09		0.26	
	Genotypes	0.06		0.20	
	Interaction	0.15		NS	
CV (%): 35.77					

4.1.9 Photosynthetic rate

The process of photosynthesis is a basic requirement of plant. It is the foremost phenomenon which drives life of plants on this Earth. The photosynthetic rate is directly related with yield. In our experiment, the photosynthetic rates did not vary significantly with change in planting densities (Table 15). However, the genotypic differences among the three different genotypes were seen which is supported by Shankar *et al*., 1990. Among the genotypes GPU-28 showed higher photosynthetic rate at flowering in all the treatments imposed. Results obtained in the experiment are in contrast to the observations made by Dwyer and Tollenaar (1989), Cox (1996) and Franic *et al*. (2015).

4.1.10 Stomatal frequency

The number of stomata per unit leaf area is one of the important components in determining the photosynthetic rate (Franks and Beerling, 2009 and Tanaka *et al.*, 2013). In present study, no particular trend has been observed in stomatal frequency (Table 16). However, with increase in the intra row spacing, there was a decrease in the stomatal frequency and also with increased plant density. These inconsistent results infer that the relevancy of plant population on stomatal frequency may not be of any significance. However, among the genotypes, GPU-28 maintained higher stomatal frequency.

4.1.11 Grain yield

Significant improvement in seed yield was observed from 30 × 15 cm to 15 × 10 cm (Table 17). Further reduction in spacing (increase in plant density) had no influence on improving the yield. The optimum spacing for highest productivity with optimum conditions like recommended dosage of fertilizers, with adequate amounts of water supply, 15 × 10cm would be best for higher yields by 19.1% compared to recommended spacing of 22.5 × 15cm. Although management practices could be difficult in 15 × 10cm, this could be helpful for farming community in broadcasting of seeds if they take up harrowing in both the directions to maintain the population of 66.7/ m^2 (6.67 lakhs/ ha).

Anitha (2015) reported that at any given age of seedling at transplanting, reduction of spacing from 30x10 cm to 20 × 20 cm have increased the grain yield significantly high which was due to increased straw weight and harvest index.

Table 15. Effect of plant spacing on photosynthetic rate at flowering in finger millet genotypes.

Treatments (cm)	Plants (No. m^{-2})	Photosynthetic rate (u Mol m^{-2} s^{-1})			Mean
		GE-292	**GPU-28**	**GE-199**	
T_1 (30 × 15)	22.2	19.67	17.63	19.33	18.88
T_2 (30 × 10)	33.3	18.73	20.27	18.53	19.18
T_3 (22.5 × 10)	44.4	16.47	20.30	18.73	18.50
T_4 (15 × 10)	66.7	15.93	18.37	18.73	17.68
T_5 (10 × 10)	100.0	16.53	20.67	17.57	18.26
T_6 (10 × 7.5)	133.3	13.30	19.10	13.63	15.34
T_7 (10 × 5)	200.0	19.40	19.67	12.50	17.19
Mean		17.15	19.43	17.01	
	Factors	**SE(m) ±**		**C.D at 5%**	
	Treatments	1.43		NS	
	Genotypes	0.94		NS	
	Interaction	2.48		NS	
CV (%): 24.17					

Table 16. Effect of plant spacing on stomatal frequency at flowering in finger millet genotypes

Treatments (cm)	Plants (No. m^{-2})	Stomatal frequency (No/mm^2)			Mean
		GE-292	**GE-199**	**GPU-28**	
T_1 (30 × 15)	22.2	45,416.7	37,916.7	48,333.3	**43,888.9**
T_2 (30 × 10)	33.3	48,333.3	54,166.7	49,166.7	**50,555.6**
T_3 (22.5 × 10)	44.4	50,833.3	45,416.7	49,583.3	**48,611.1**
T_4 (15 × 10)	66.7	45,833.3	40,416.7	39,583.3	**41,944.5**
T_5 (10 × 10)	100.0	44,166.7	47,500	49,583.3	**47,083.3**
T_6 (10 × 7.5)	133.3	45,000	42,916.7	58,333.3	**48,750**
T_7 (10 × 5)	200.0	42,083.3	52,500	45,000	**46,527.8**
Mean		**45,952.4**	**45,833.3**	**48,511.9**	
	Factors	**SE(m) ±**		**C.D at 5%**	
	Treatments	2226.0		4515.5	
	Genotypes	1457.3		NS	
	Interaction	3855.5		7821.06	
CV (%): 10.09					

Table 17. Effect of plant spacing on grain yield of finger millet genotypes

Spacing Treatments (cm)	Hills m^{-2}	Grain yield (g. m^{-2})			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	556.0	623.	662.6	**614**
T_2 (30 × 10)	33.3	718.7	635.7	581.2	**645.2**
T_3 (22.5 × 10)	44.4	745.2	782.7	685.3	**737.7**
T_4 (15 × 10)	66.7	776.3	776.5	711.1	**754.7**
T_5 (10 × 10)	100	661.5	774.1	665.6	**700.4**
T_6 (10 × 7.5)	133.3	737.2	648.9	717.6	**701.2**
T_7 (10 × 5)	200	730.8	746.	750.6	**742.5**
Mean		**703.7**	**712.5**	**682.0**	
	Factors	**SEm ±**		**CD @ 5 %**	
	Spacing	29.2		83.7	
	Varieties	19.1		NS	
	Interaction	50.5		NS	
C.V. (%): 12.5					

Further Maobe *et al.* (2014) also reported that plant densities less than 333333 plants per ha (30 × 10 cm) will reduce the grain yield significantly. Wherein they have also shown that plant densities above 10 lakh/ha (100 hills m^{-2}) significantly reduce panicle weight and grain weight. Therefore, optimum could be from 3.3 to 4 lakhs. However, in our results it can go up to 6.6 lakhs/ha (Table 17).

Roy *et al.* (2001) have shown that reduction in intra-row spacing from 10 to 6 cm have decrease the yield significantly keeping the same spacing between the rows (25cms). This signifies the intra-row competition. Similarly, in our study, keeping the same inter-row spacing of 10 cm with higher intra-row spacing was relatively better for seed yield when compared to lower intra-row spacing (Table17). With no importance to intra row spacing, increasing row spacing from 20 to 50 cm has increased the grain yield of finger millet significantly. (Dereje *et al.*, 2016). However, Shinggu and Gani (2012) reported that increase in inter row spacing from 10 to 20 cm have decreased the grain yield in one season. In the other season it was the other way around. However, Kalaraju *et al*. (2009) showed that square planting could be better when compared to uneven spacings. Hence as per our results 15 × 15 cm or 15 × 10 cm could be better for higher yields.

4.1.12 Productive tillers

The productive tillers per unit area is the important trait in determining the grain yield in finger millet (Anon., 2017). With increase in planting density, in all the genotypes the number of tillers produced increased two-fold by 30 × 15 cm to 15 × 10 cm and onwards. The number of tillers were higher in 15 × 10 cm by 51.4 % compared to the recommended package of 22.5 × 10 cm. Further there is no marked improvement in productive tillers although, highest (236.3 tillers/m^2) were observed in 10 × 5 cm spacing (Table 18). In continuation, progressive significant reduction in tiller no/ hill was observed from spacing of 30 × 15 cm (4.338) to 10 × 5 cm (1.183) (Table 19). It is the number of tillers which is more important in unit area rather than number/hill. Therefore, as there are no significant differences between the recommended package and 15 × 10 cm spacing, 15 × 10 cm would be optimum as it has both higher number/m^2 with an optimal number/hill (2.86).

Table 18. Effect of plant spacing on productive tillers (No. m^{-2}) of finger millet genotypes

Spacing Treatments (cm)	Hills m^{-2}	Productive tillers (No. m^{-2}) GE-292	GE-199	GPU-28	Mean
T_1 (30 × 15)	22.2	100. 7	88.3	100.0	**96.3**
T_2 (30 × 10)	33.3	111. 7	105.0	102.7	**106.4**
T_3 (22.5 × 10)	44.4	127. 0	137.7	119.7	**128.1**
T_4 (15 × 10)	66.7	213.4	183.7	175.6	**190.9**
T_5 (10 × 10)	100	229.0	190.0	199.0	**206.0**
T_6 (10 × 7.5)	133.3	233.7	196.9	219.8	**216.8**
T_7 (10 × 5)	200	244.3	216.2	248.5	**236.3**
Mean		**180.0**	**159.7**	**166.5**	
	Factors	**SEm ±**		**CD @ 5 %**	
	Spacing	4.9		14.1	
	Varieties	3.2		9.2	
	Interaction	8.5		24.4	
C.V. (%): 8.7					

Table 19. Effect of plant spacing on productive tillers (No. hill^{-1}) of finger millet genotypes

Spacing Treatments (cm)	Hills m^{-2}	Productive tillers (No. hill^{-1})			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	4.5	4.0	4.5	**4.3**
T_2 (30 × 10)	33.3	3.3	3.1	3.1	**3.2**
T_3 (22.5 × 10)	44.4	2.9	3.1	2.7	**2.9**
T_4 (15 × 10)	66.7	3.2	2.7	2.6	**2.9**
T_5 (10 × 10)	100	2.3	1.9	2.0	**2.1**
T_6 (10 × 7.5)	133.3	1.8	1.5	1.6	**1.6**
T_7 (10 × 5)	200	1.2	1.1	1.2	**1.2**
Mean		**2.75**	**2.50**	**2.54**	
	Factors	**SEm +**		**CD @ 5 %**	
	Spacing	0.066		0.19	
	Varieties	0.043		0.12	
	Interaction	0.115		0.33	
C.V. (%): 7.72					

4.1.13 Mean ear weight

The mean ear weight is the next most important yield determining trait after productive tillers (Anon., 2017). In the present experiment decrease in spacing (increased plant density) significantly reduced the mean ear weight from 8.047 (30 × 15 cm) to 3.888 (10 × 5 cm). The mean ear weight was 2 grams low from 22.5 × 10 cm to a decreased spacing of 15 × 10 cm (Table 20) (29.8% reduction). However, increased productive tillers tiller number was 51.4%. Therefore, 15 × 10 cm spacing may be optimum to have higher productivity.

4.1.14 Test weight

Test weight is one of the important trait considered to contribute to the yield. It is the prime trait after the productive tillers and mean ear weight (Anon., 2017). In the present study the increase in the planting density (decreased spacing) had no significant influence on the test weight of the finger millet genotypes. However, the means of the treatments varied with a ranger from 3.47 (30 × 15cm) to 3.29 (10 × 5cm). (Table 21). Although, there are differences between the genotypes as the genotypes differed in their inherent capability to produce and yield. This infers that the test weight cannot be altered through an environmentally driven phenomenon. Our results are in comparison with the findings of Asmamaw (2017).

4.1.15 Spikelet fertility

Spikelet fertility is the primary component which ultimately results in the grain filling of spikes. Fertility of spikes in the finger determines the quality of grains and number of grains filled in the spike. In our study, spikelet fertility was calculated based on the number of spikes and florets. The spacing had no significant effect on the spikelet fertility of the fingers. However, there were differences for the genotypes. The maximum fertility was seen in GPU-28 which was seen under the recommended spacing of 22.5 × 10cm (Table 22) and there was no significant difference between planting densities 22.5 × 10cm and 15 × 10cm. This infers that spikelet fertility does not get affected by alteration of planting densities.

Table 20. Effect of plant spacing on mean ear weight in finger millet genotypes

Spacing Treatments (cm)	Hills m^{-2}	Mean ear weight (g)			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	6.95	8.89	8.30	**8.05**
T_2 (30 × 10)	33.3	6.92	7.61	7.10	**7.21**
T_3 (22.5 × 10)	44.4	6.83	7.21	7.20	**7.08**
T_4 (15 × 10)	66.7	4.56	5.28	5.07	**4.97**
T_5 (10 × 10)	100	3.62	4.80	4.20	**4.21**
T_6 (10 × 7.5)	133.3	3.94	4.27	4.10	**4.11**
T_7 (10 × 5)	200	3.74	4.17	3.75	**3.89**
Mean		**5.23**	**6.04**	**5.67**	
	Factors	**SEm ±**		**CD @ 5 %**	
	Spacing	0.29		0.63	
	Varieties	0.14		0.41	
	Interaction	0.38		NS	
C.V. (%): 11.6					

Table 21. Effect of plant spacing on test weight of finger millet genotypes

Spacing Treatments (cm)	Hills m^{-2}	Test weight (g/ 1000 seeds)			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	3.29	3.10	4.05	**3.48**
T_2 (30 × 10)	33.3	3.25	3.12	4.11	**3.49**
T_3 (22.5 × 10)	44.4	3.27	2.99	3.86	**3.37**
T_4 (15 × 10)	66.7	3.10	3.20	3.71	**3.34**
T_5 (10 × 10)	100	3.08	3.28	3.68	**3.35**
T_6 (10 × 7.5)	133.3	3.05	2.97	3.84	**3.29**
T_7 (10 × 5)	200	3.07	2.99	3.82	**3.29**
Mean		**3.16**	**3.09**	**3.87**	
	Factors	**SEm ±**		**CD @ 5 %**	
	Spacing	0.05		0.15	
	Varieties	0.04		0.10	
	Interaction	0.10		NS	
C.V. (%): 4.8					

Table 22. Effect of plant spacing on spikelet fertility in finger millet genotypes

Spacing Treatments (cm)	Hills m^{-2}	Spikelet fertility (%)			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	80.8	86.8	75.7	**81.1**
T_2 (30 × 10)	33.3	82.1	76.6	74.9	**77.8**
T_3 (22.5 × 10)	44.4	77.0	93.0	73.6	**81.2**
T_4 (15 × 10)	66.7	74.4	80.6	78.4	**77.8**
T_5 (10 × 10)	100	64.4	76.8	75.9	**72. 4**
T_6 (10 × 7.5)	133.3	74.5	87.0	75.5	**79.0**
T_7 (10 × 5)	200	64.3	81.5	65.1	**70.3**
Mean		**73.9**	**83.2**	**74.1**	
	Factors	**SEm ±**		**CD @ 5 %**	
	Spacing	1.77		5.1	
	Varieties	1.16		3.31	
	Interaction	3.07		8.8	
C.V. (%): 6.89					

4.1.16 Total biomass

Total biomass produced by the plant is one of the measure of the plant productivity. Biomass has a vital role in the plant yield and development as it contributes for the harvest index of the variety. In our study, the biomass is decreased as the plant spacing was modulated from the current recommended spacing 22.5 × 10cm. however, the biomass was highest (2194.2 $g.m^2$) at 15 × 10cm spacing. The greater biomass was hovering around the square plantings. There were significant differences between the treatments and also for the genotypes. The variety GPU-28 recorded greater biomass than the other two genotypes used in the study. Our results infer that the biomass follows the sigmoidal pattern with respect to the differences in the plant densities (Table 23).

1.1.17 Harvest index

Harvest index is one of the indicators of the reproductive efficiency of a crop. It is the reflection of the partitioning co-efficiency of assimilates from the vegetative plant part to the grain (Sinclair, 1998). Present study indicated that the varied spacing had no influence on the harvest index of the varieties (Table 24). However, the genotypic differences were seen among the genotypes. Genotype GE-199 had greater harvest index of 0.407 in two spacings. These results are in line with the findings of Prem *et al*. (2014).

4.2 Effect of nitrogen levels on tillering behaviour in finger millet

4.2.1 Seed germination

Seed germination is one the primary morphological event that determines the crop stand and productivity. In the sand culture medium (no soil impediment; devoid of other contaminants), the seed germination started on 2ndday (66.7 %) and reached 87.5 and 100 % on the third and fourth day, respectively (Table 25). Soaking of seeds in 1% urea solution overnight resulted in 100% seed germination by second day itself (Table 25) and this concentration for seed priming could be optimum. The seed priming could help to repair of membrane damage if any and to initiate rapid seed germination (Rahimi, 2013). However, prior imbibition of seed with higher concentration of urea (2% or 3%) or higher nitrogen content in the medium delayed the seed germination although it reached

Table 23. Effect of plant spacing on total biomass in finger millet genotypes

Spacing Treatments (cm)	Hills m^{-2}	Biomass (g. m^{-2})			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	1547.8	1533.5	2056.3	**1712.5**
T_2 (30 × 10)	33.3	1745.4	1598.3	2019.4	**1787.7**
T_3 (22.5 × 10)	44.4	1837.7	1932.2	2437.4	**2069.1**
T_4 (15 × 10)	66.7	2438.5	2036.1	2108.1	**2194.2**
T_5 (10 × 10)	100	2199.2	2122.7	2097.5	**2139.8**
T_6 (10 × 7.5)	133.3	2206.0	1789.8	2146.8	**2047.5**
T_7 (10 × 5)	200	2026.1	1878.5	2008.5	**1971.0**
Mean		**2000.1**	**1841.6**	**2124.9**	
	Factors	**SEm ±**		**CD @ 5 %**	
	Spacing	59.1		169.7	
	Varieties	38.7		111.1	
	Interaction	102.4		293.8	
C.V. (%): 8.9					

Table 24. Effect of plant spacing on harvest inde × in finger millet genotypes

Spacing Treatments (cm)	Hills m^{-2}	Harvest index			Mean
		GE-292	GE-199	GPU-28	
T_1 (30 × 15)	22.2	0.36	0.41	0.32	**0.36**
T_2 (30 × 10)	33.3	0.41	0.40	0.29	**0.37**
T_3 (22.5 × 10)	44.4	0.41	0.41	0.28	**0.36**
T_4 (15 × 10)	66.7	0.32	0.38	0.34	**0.34**
T_5 (10 × 10)	100	0.30	0.37	0.32	**0.33**
T_6 (10 × 7.5)	133.3	0.33	0.36	0.33	**0.34**
T_7 (10 × 5)	200	0.36	0.40	0.37	**0.38**
Mean		**0.36**	**0.39**	**0.32**	
	Factors	**SEm ±**		**CD @ 5 %**	
	Spacing	0.013		NS	
	Varieties	0.008		0.02	
	Interaction	0.02		0.06	
C.V. (%): 8.8					

Table 25. Effect of nitrogen on seed germination in finger millet (Cv. GPU-28)

DAS	Seed germination (%)						Mean
	C	1% Urea	2% Urea	3% Urea	2N	3N	
1	0	0	0	0	0	0	**0**
2	75	100	50	25	75	75	**66.7 ± 10.5**
3	100	100	75	50	100	100	**87.5 ± 8.5**
4	100	100	100	100	100	100	**100.0 ± 0**

Note:

C = Control (grown in complete Hoagland solution)

1 % Urea = Seeds were soaked in 1 % urea and grown in Hoagland solution

2 % Urea = Seeds were soaked in 2 % urea and grown in Hoagland solution

3 % Urea = Seeds were soaked in 3 % urea and grown in Hoagland solution

2 N = Seeds were sown directly in pots kept in Hoagland solution with additional 1 M nitrogen.

3 N = Seeds were sown directly in pots kept in Hoagland solution with additional 2 M nitrogen.

100% on 4 DAS (Table 25). The excess nitrogen might produce higher ROS and hence delayed the seed germination (Sarkar *et al*., 2011). Further, it was also suggested that higher levels of nitrogen (urea) might produce ammonia (harmful for seed germination) due to hydrolysis of urea by urease present in seed (Bremner and Krogmeier, 1989). These results infer that the soaking of seeds in 1% urea will be helpful in advancing the seed germination. This will be advantageous for rainfed agriculture where the top soil moisture will generally be depleted within 2-3 days of seed sowing.

4.2.2 Tillering pattern

Early tillering (10thday) was started with 3 times of nitrogen in the growth medium and by 13th day all the N treatments (priming with urea or direct application) gave 100% tillering except the control which took 15 days for complete tillering (Table 26). These results infer that, application of 3 times of N or if the soil is having enough nitrogen, the tillering starts early by 3 days. The early tillering with higher nitrogen (by soaking or additional application of N) might be due to the increase in chlorophyll content and carbohydrates in the internode region of the plant which provide assimilates needed from the node from which the tiller is exerted (Tanaka and Garcia, 1965). There is a direct relationship between the concentration of nitrogen present in the culm of the plant and the tillering. Similar, observations of early tillering were observed with application of higher N (Patil *et al*., 2015). However, N above 40 kg ha^{-1}has no advantage in tiller production (Yadav *et al*., 2010; Simakumari, 2011). These results reiterates that an optimum N is essential for early and higher tiller production in finger millet.

4.2.3 Number of tillers/ hill

The first tiller production was observed on 10thDAS with a higher number in 3 times of nitrogen (1.25 tillers hill^{-1}). Such tiller production reached to 2 per hill by 13thDAS in all the treatments except the control, which received recommended nitrogen (Table 27). These results indicate the adequate level of nitrogen (40 kg ha^{-1}, the recommended dose) could be enough for proper tiller production (Yadav *et al*., 2010; Simakumari, 2011). However, higher nitrogen results in early tiller production. Positive effect of nitrogen on tillering is associated with promotion of cell division (Mc Adam

Table 26. Effect of nitrogen on tillering at different levels of treatments

DAS	Tillering (%)							
	Control	1% Urea	2% Urea	3% Urea	2N	3N	STDEV	SE
10 DAS	0	0	0	0	0	50	20.4	7.72
11 DAS	0	25	50	50	50	75	25.8	9.76
12 DAS	0	75	75	75	75	100	34.2	12.91
13 DAS	50	100	100	100	100	100	20.4	7.72
14 DAS	75	100	100	100	100	100	10.2	3.86
15 DAS	100	100	100	100	100	100	0.00	0.00
16 DAS	100	100	100	100	100	100	0.00	0.00

Table 27. Effect of nitrogen on tiller production with time

Treatment	Tillers hill^{-1}				
	10 DAS	11 DAS	12 DAS	13 DAS	14 DAS
CONTROL	1.0	1.0	1.0	1.5	1.75
1% UREA	1.0	1.25	1.75	2.0	2.0
2% UREA	1.0	1.5	1.75	2.0	2.0
3% UREA	1.0	1.5	1.75	2.0	2.0
2 N	1.0	1.5	1.75	2.0	2.0
3 N	1.25	1.75	2.0	2.0	2.0
Mean	**1.05**	**1.42**	**1.67**	**1.92**	**1.96**

et al., 1989; Mc Kenzie, 1998), as the nitrogen has mediatory role in tiller production through cytokinin production in roots for more absorption of nitrogen (Tomlinson and Connor, 2004) and, by maintaining higher cytokinin to IAA ratio (Chan *et al*., 1998). Hence, treating seeds with nitrogen would be useful for early tillering in addition to early seed germination, which is indeed highly useful under rainfed situations.

4.2.4 Plant height

The plant height progressively increased from 15 DAS (8.06 cm) to 30 DAS (9.7 cm). At all the stages of measurement of plant height, imbibing the seed with 2% urea gave higher shoot length compared to the other treatments and 2% urea was superior to the control suggesting that imbibing the seed in urea may help for increased plant height when the soils will be deficit with the nitrogen. This could be like the seed hardening treatment for inducing the drought tolerance. These results further suggest that application of 2 or 3 times of N have no significance in increasing the seedling height by 2N or 3N. Our results are in line with the findings of Jena *et al.* (2016) wherein they have shown that the plant height is directly influenced by the concentration of nitrogen. The increase in the plant height was attributed to the increased chlorophyll content and the specific activity of enzymes involved in nitrogen uptake. Therefore, imbibition could be a better proportion for improving the plant height and it should be less than 2% urea (Table 28).

4.2.5 Seedling traits

The basal internode length was increased from control (3.1 cm) to seeds soaked in 2 % urea solution (4.1 cm). However, further increase nitrogen concentration found to reduce the internode length. However, there are no marked differences in stem thickness between the nitrogen levels, although highest thickness was observed in seeds soaked with 2 % urea solution. By 30th DAS, all the treatments produced equal number of tillers with no significant differences between the treatments. The number of leaves per hill were increased up to 2 % urea; further increase in nitrogen decreased the leaf number, which extended for leaf area, root and shoot length and their respective dry weights (Table 29).

Table 28. Effect of nitrogen on plant height in finger millet seedlings

Treatment	Seedling height (cm)			
	15 DAS	**20 DAS**	**25 DAS**	**30 DAS**
CONTROL	8.13	8.70	9.25	9.73
1% UREA	8.70	9.33	9.75	10.28
2% UREA	8.60	9.90	10.45	10.93
3% UREA	7.80	9.35	10.15	10.33
2 N	7.55	7.90	8.23	8.55
3 N	7.53	7.83	8.13	8.40
Mean	**8.06**	**8.84**	**9.33**	**9.70**
SEm ±	0.20	0.10	0.16	0.28
CD @ 5 %	0.59	0.31	0.47	0.85
C.V. (%)	4.8	2.30	3.4	5.83

Table 29. Effect of nitrogen on growth parameters on 30 DAS in finger millet

Treatment	Ist internode (cm)	Basal stem thickness (cm)	Tillers/hill	No. of leaves/hill	Leaf area (cm^2/plant)	Root length (cm)	Shoot length (cm)	Root dry weight (mg/ hill)	Shoot dry weight (mg/ hill)	Total biomass (mg/ hill)
CONTROL	3.1	3.8	1.8	7.3	139.48	15.6	10.3	0.12	0.32	0.44
1% UREA	3.5	4.3	2.0	12.0	201.43	17.8	10.3	0.14	0.43	0.57
2% UREA	4.1	4.8	2.0	13.5	219.13	17.1	11.1	0.22	0.52	0.74
3% UREA	3.5	4.4	2.0	11.5	183.78	16.3	10.3	0.22	0.37	0.59
2 N	3.3	4.4	2.0	11.3	180.00	16.6	10.8	0.18	0.42	0.60
3 N	2.8	4.2	2.0	12.3	182.93	14.1	8.1	0.25	0.49	0.74
Mean	**3.38**	**4.32**	**1.97**	**11.32**	**184.45**	**16.3**	**10.2**	**0.19**	**0.43**	**0.61**
SEm+	0.186	0.18	0.10	0.45	2.50	0.48	0.23	0.02	0.026	0.035
CD @ 5 %	0.558	0.54	NS	1.33	7.50	1.44	0.7	0.06	0.077	0.10
C.V. (%)	11.0	8.30	10.42	7.88	2.71	5.93	4.6	21.1	12.1	11.3

V SUMMARY

Finger millet is an important millet crop grown extensively in rainfed areas in India. Majority area and production is contributed by the state of Karnataka. Finger millet production has been improved by the breeding efforts but reached a yield plateau of nearly 40 quintals ha^{-1} in recent years. Among the yield attributes, productive tillers followed by mean ear weight and the test weight are highly important. The major area (70%) in finger millet is occupied with the variety GPU-28, which is a shy tillering type (2.5 tillers $hill^{-1}$) with 60-80 productive tillers m^{-2} and fairly good ear size and grain size. One of the ways to break the plateaued grain yield of GPU-28 could be through the enhanced tiller number. Manipulation of tiller number is possible mainly through environmental variables which could be productive tillers, nutrition etc. Therefore, we have planned to increase the tiller number /unit area by altering the spacing (plant population).

Objective 1: To assess the physiological basis of tiller production in shy and profusely tillering genotypes with differing plant densities.

Increased plant population / plant density with reduced spacing did not affect the flowering. Increased plant density marginally improved the plant height. Increased plant density (15 x 10 cm as compared to the recommended spacing of 22.5 x 10 cm), increased the tiller production, leaf area index and SLW. Further increase in plant population / density (spacing below 15 x 10 cm) did not improve these parameters rather the chlorosis of basal leaves was increased. Across the genotypes, the increased plant density by decreased spacing from the recommended 22.5 x 10 cm to 15 x 10 cm has increased the productive tiller number from 128 to 191 tillers m^{-2} at harvest and resulted in marginal increase in yield (2.3%). Their LAI was 6.58 to 7.50. The Cv. GPU-28 had LAI of 7.96 and 6.34 with an yield of 685.3 and 711.1 g m^{-2} respectively at the spacing of 22.5 x 10 cm and 15 x 10 cm respectively. This study clearly indicates that the optimum leaf area index could be around 6.0 to 7.0 for potential yield of finger millet particularly in popular Cv. GPU-28. Hence the recommended spacing of 22.5 x 10 cm would be optimum for higher yield as well as management practices.

Objective 2: To determine the optimum nutritional factors (nitrogen) for maximising the tiller production in Cv. GPU-28.

With an intension of increasing early tillering to achieve more productive tillers in shy tillering variety GPU-28, one of the important factors, the nutrition (nitrogen) that influences the productivity was investigated under the control conditions (Hoagland solution culture). Compared to the recommended nitrogen level, increased nitrogen through direct application or by seed hardening with nitrogenous fertilizer (Urea) produced early tillering by 3-4 days. Tthe seedling length and plant height was increased substantially with additional nitrogen (2% urea). The additional nitrogen (2% urea) enhanced the basal stem thickness, internodal length, number of leaves; leaf area and seedling dry weight. Higher concentrations reduced these parameters effectively. Therefore, compared to the normal fertilization of nitrogen, additional nitrogen priming would be better for increasing seedling vigour.

Future line of work

1. Strategies to increase the tiller number per hill at the recommended spacing of 22.5 x 10 cm can be investigated.
2. The recommended spacing (22.5 x 10 cm) with maximum tillering potential using other inputs may be compared with "Guli method of planting, 30 x 30 cm" for yield potential.

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