Int.J.Curr.Microbiol.App.Sci (2020) *9*(5): 1535-1547

EXCELLENT PUBLISHERS

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 9 Number 5 (2020)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2020.905.174

Optimum LAI for Yield Maximisation of Finger Millet under Irrigated Conditions

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Keywords

Plant density, leaf area, photosynthetic rate, productive tillers, grain yield

Article Info

Accepted:
10April 2020
Available Online:
10 May 2020

A B S T R A C T

Field experiment was conducted during summer, 2018 to determine the influence of LAI on yield maximisation in finger millet genotypes by varying plant densities. Maximum grain yield was obtained at the plant density of 44.4 to 66.6 hills m^{-2} but above or below. The source size (LAI) and source activity (photosynthetic rate) were not the limitations for yield maximisation under optimal irrigation and; LAI of 6.5 to 7.0 was optimum for maximum finger millet yield especially in variety, GPU-28. The sink traits, namely productive tillers per m^{-2} and mean ear weight were compensated to each other (r = -0.967***). The plant density of 44.4 hills m^{-2} (22.5 cm x 10 cm) could be optimum for irrigated finger millet. Further yield enhancement could be possible by increasing productive tillers (up to 5.0 per hill) with plant density of 44.4 hills m^{-2} varying spacing to 30.0 cm x 7.5 cm.

Introduction

Finger millet is a C_4 crop belongs to family poaceae (Dida *et al.*, 2007) cultivated in arid and semi-arid regions in more than 25 countries. In India as a staple food and fodder crop, it is cultivated an area of 1.19 million hectares with a production of 1.98 lakh tones and productivity of 1661 kg ha^{-1}, Karnataka being the major producer to the extent of 58 per cent (Anon., 2015; Sakamma *et al.*, 2018).

Although finger millet is cultivated as rainfed crop by more than 90% area (Davis *et al.*, 2019), crop being responsive to irrigation and external fertilizer application (Gull *et al.*, 2014; Thilakarathna and Raizada, 2015; Ramakrishnan *et al.*, 2017; Wafula *et al.*, 2018), it is cultivated during summer season wherever irrigation facilities are available. Finger millet is highly nutritious crop with its composition of protein (7.3%), fat (1.3%), carbohydrates (72.6%), dietary fibre (18%), Ash (3.0%), calcium (352mg/100g) and Leucine, 594 mgg^{-1} of protein (Shobana *et al.*, 2013; Devi *et al.*, 2014; Chandra *et al.*, 2016; Gupta *et al.*, 2017; Sharma *et al.*, 2017). In addition, it has high soluble fibre, polyphenols coupled with high resistant starch, thus slow hydrolysis of starch and; gaining importance with increasing diabetic population (Kumari and Sumathi, 2002).

For yield improvement of finger millet, early research efforts were made to select large ear size as the tiller number was not a constraint (8.0 tillers $hill^{-1}$ in popular varieties at that time, Krishnamurthy, 1971). Probably, selection for ear size with time, the tiller numbers might have compensated with ear size and resulted in selection of shy tillering genotypes. It is clearly evident in the popular variety GPU-28 which has only 2 to 2.5 tillers $hill^{-1}$ with a mean ear weight of 6.0 to 7.0 g (Prakasha *et al.*, 2018). In recent years, it was observed that the major yield attributes in finger millet are the productive tillers (contributes to 54 % of yield), followed by ear weight and test weight although it is genotypic character (Anon., 2015). Increase in productive tillers per unit land area can be achieved by manipulating the population density (Richards, 2000). Therefore, additional productive tiller per hill could enhance the potential yield of GPU-28.

Formation of productive tillers and consequent grain yield of finger millet are determined by the source size and activity. The source size in finger millet is not a major limitation as a cereal crop (Patrick, 1988) and the photosynthetic rate is also relatively high being a C_4 species (Berdahl *et al.*, 1971; Ueno *et al.*, 2006). Hence, tiller production is an important sink trait in determining the grain yield which can be addressed though manipulating the planting density under adequate irrigation and soil fertility. Therefore, the optimum source size (LAI) and productive tillers required for maximum grain yield in finger millet was investigated with varying plant densities.

Materials and Methods

The experiment was conducted during summer, 2018. Three finger millet genotypes (GE-292, GE-199 and GPU-28) were evaluated in factorial RCBD comprising of seven spacing treatments (given with data) in four replications. Experiment was conducted at the Field Unit, Department of Crop Physiology, Zonal Agricultural Research Station, GKVK, University of Agricultural Sciences, Bengaluru-65. The finger millet genotypes were sown on 12/01/2018 in plastic portrays and 17 days old seedlings were transplanted in the main field (29/01/2018) in five rows of 1.2 meter length with respective spacings as per the treatments.

At the time of flowering, observations on leaf area, light penetration, chlorosis of older leaves and photosynthetic rate were measured. The 3rd leaf area (length x width x 0.75) was multiplied by total number of leaves in all the tillers in a hill to arrive at leaf area per plant. The leaf area index (LAI) was computed by dividing the total leaf area with the spacing per hill according to the treatments. The light insolation at ground level (light penetrated to the ground) was recorded by placing the light quantum sensor (Li-Cor) between the rows. The number of basal leaves turned yellow (more than half part of the leaf becomes chlorotic) on the main tiller was counted at 20 days after anthesis. The photosynthetic rate was measured using Infrared Gas Analyser (IRGA) (Cyrus) from 9.00 to 11.00 AM on 20th day after flowering. The yield attributes *viz.*, productive tillers, mean ear weight and test weight were measured at the time of harvest. All these measurements were made in net plot area of three rows of 1.0 meter row length and computed to per square meter area. The spikelet fertility was calculated by cutting 2cm finger length and carefully counted the number of florets and seeds. The fertility was then calculated as the number of filled grains / total number of florets multiplied by 100. The data was statistically analysed in factorial RBD using OPSTAT (Sheoran *et al.,* 1998).

Results and Discussion

Early efforts on yield improvement of finger millet were basically through selection for large ear size, wherein productive tillers per hill was not a constraint (Krishnamurthy, 1971). Next stage of improvement was through plant breeding efforts for blast resistance combined with adoption of improved management practices. In recent years, finger millet yield has reached a plateau (Swetha, 2011). Among the cultivated varieties, most popular variety GPU-28 is a shy tillering type with relatively a large ear size (Prakasha *et al.,* 2018). Therefore, the plant density was altered to increase the leaf area, productive tillers and consequent grain yield of finger millet.

The plant density of 44.4 m^{-2} (recommended spacing of 22.5 cm x 10cm) resulted in higher grain yield of 737.7 g m^{-2} over the plant density of 33.3 m^{-2} (645.2g m^{-2}) and 22.2 m^{-2} (613.0 g m^{-2}). The higher plant density (66.7 m^{-2}) and more did not increase the grain yield significantly (Table 1). Similarly, increase in row spacing from 20 to 30 cm (Bitew and Asargew, 2014; Dereje *et al.,* 2016) and row spacing up to 45 cm (Yoseph, 2014) have increased the grain yield significantly; with no significant differences between 30 and 45 cm row spacing (Yoseph, 2014). The plant density with higher spacing of 45 cm and above between the rows decreased the grain yield due to reduced number of tillers per unit area (Bitew and Asargew, 2014; Dereje *et al.*, 2016). Therefore, the optimum spacing could be between 20 to 30 cm between rows and 7.5 to 10 cm between the plants. The increased grain yield was due to increased total biomass production (r = 0.457*, Table 2) with no influence of harvest index (HI) as HI did not differ between treatments (Table 1). Similarly significant positive association between biomass and grain yield has been reported (Negi *et al.,* 2017; Prakasha *et al.,* 2018; Nanja Reddy *et al.,* 2019; Chavan *et al.*, 2020; Somashekhar and Loganandhan, 2020). Such biomass production will be determined by the LAI and photosynthetic rate.

The LAI (source size) showed a positive significant relationship with biomass (r = 0.803**), productive tillers (r = 0.687**) and grain yield (r = 0.528*) (Table 2). The mean grain yield was increased with an increase in LAI up to 7.0, beyond which the grain yield was decreased (Fig. 1a). Among the varieties, GPU-28 gave the grain yield of 685.3 g m^{-2} at the recommended spacing of 22.5 cm x 10 cm (LAI of 7.96), while narrow spacing (15 cm x 10 cm) marginally increased the grain yield (711.1 g m^{-2}, the LAI was 6.34) and further increase in plant density (up to 200.0 m^2 by 10 cm x 5 cm) did not result in higher grain yield significantly (Table 1).

These results imply that the optimum LAI for higher grain yield could be between 6.5 and 7.0 especially in case of variety, GPU-28. At plant density above 44.4 m^{-2}, the light penetration to the ground level was decreased with an increased chlorosis of older leaves (Table 3). Probably, at narrow spacing with higher LAI, the microclimate has poor aeration and lead to higher maintenance respiration, and reduced grain yield by reducing the partitioning (harvest index). The wider spacing reduced the LAI significantly as compared to the recommended spacing (22.5 cm x 10 cm), biomass production and grain yield.

Table.1 Effect of plant densities on biomass, harvest index and grain yield in finger millet genotypes

Spacing (cm x cm) / Varieties	**Plant density (No. m^{-2})**	**Biomass (g m^{-2})**				**Harvest index**				**Grain yield (g m^{-2})**			
		GE-292	GE-199	GPU-28	Mean	GE-292	GE-199	GPU-28	Mean	GE-292	GE-199	GPU-28	Mean
T_1 (30 x 15)	22.2	1548	1534	2056	**1713**	0.36	0.41	0.32	**0.36**	556.0	623.2	662.6	**613.9**
T_2 (30 x 10)	33.3	1745	1598	2019	**1788**	0.41	0.40	0.29	**0.37**	718.7	635.7	581.2	**645.2**
T_3 (22.5 x 10)	44.4	1838	1932	2437	**2069**	0.41	0.41	0.28	**0.36**	745.2	782.7	685.3	**737.7**
T_4 (15 x 10)	66.7	2439	2036	2108	**2194**	0.32	0.38	0.34	**0.34**	776.3	776.5	711.1	**754.7**
T_5 (10 x 10)	100.0	2199	2123	2098	**2140**	0.30	0.37	0.32	**0.33**	661.5	774.1	665.6	**700.4**
T_6 (10 x 7.5)	133.3	2206	1790	2147	**2048**	0.33	0.36	0.33	**0.34**	737.2	648.9	717.6	**701.2**
T_7 (10x 5)	200.0	2026	1879	2009	**1971**	0.36	0.40	0.37	**0.38**	730.8	746.1	750.6	**742.5**
Mean		**2000**	**1842**	**2125**		**0.36**	**0.39**	**0.32**		**703.7**	**712.5**	**682.0**	
Factors		SEm±	C.D @t 5%			SEm±	CD @ 5 %			SEm±	CD @ 5 %		
Treatments		59	170			0.01	NS			29.2	83.7		
Genotypes		39	111			0.01	0.02			19.1	NS		
Interaction		102	294			0.02	0.06			50.5	NS		
C.V (5%)		8.9				8.8				12.5			

Table.2 Correlation between grain yield and yield attributing traits across the plant densities and genotypes of finger millet

	(1) LAI	(2) LI	(3) Chlo.	(4) Photosy.	(5) PT	(6) MEW	(7) TW	(8) Spike	(9) HI	(10) Biomass	(11) GY
(1) LAI	1.000										
(2) Light penetration	-0.637	1.000									
(3) Chlorosis	0.556	-0.507	1.000								
(4) Photosynthetic rate	-0.317	0.381	-0.337	1.000							
(5) Prod. Tillers m^{-2}	0.687	-0.677	0.875	-0.505	1.000						
(6) Mean ear weight	-0.642	0.668	-0.836	0.439	-0.967	1.000					
(7) Test weight	-0.188	-0.349	-0.315	-0.195	-0.210	0.180	1.000				
(8) Spikelet fertility	-0.539	0.439	-0.459	0.441	-0.492	0.478	-0.311	1.000			
(9) HI	-0.461	0.561	-0.043	0.242	-0.188	0.242	-0.570	0.521	1.000		
(10) Total biomass	0.803	-0.809	0.239	-0.347	0.505	-0.470	0.317	-0.484	-0.720	1.000	
(11) Grain yield	0.528	-0.457	0.356	-0.217	0.536	-0.424	-0.269	-0.034	0.277	0.457	1.000

Note: r – value more than 0.433 and 0.549 are significant at 5 and 1 % respectively

Table.3 Effect of plant densities on leaf area index (LAI), light penetration and leaf chlorosis in finger millet genotypes

Spacing (cm x cm) / Varieties	**Plant density (No. m^{-2})**	**LAI at flowering**				**Light penetration (μ molm^{-2}s^{-1}) at flowering**				**Leaf chlorosis at 20 DAF (No. of chlorotic leaves per main tiller)**			
		GE-292	GE-199	GPU-28	Mean	GE-292	GE-199	GPU-28	Mean	GE-292	GE-199	GPU-28	Mean
T_1 (30 x 15)	22.2	4.61	4.17	5.18	**4.65**	146.5	163.9	44.3	**118.2**	0.11	0.11	0.00	**0.07**
T_2 (30 x 10)	33.3	5.65	4.25	5.80	**5.23**	115.6	175.4	53.4	**114.8**	0.00	0.00	0.00	**0.00**
T_3 (22.5 x 10)	44.4	5.76	6.04	7.96	**6.58**	60.9	69.6	18.1	**49.5**	0.33	0.11	0.00	**0.15**
T_4 (15 x 10)	66.7	9.27	6.88	6.34	**7.50**	42.3	62.4	31.8	**45.5**	0.56	0.44	0.22	**0.41**
T_5 (10 x 10)	100.0	8.64	7.25	5.67	**7.19**	35.2	48.4	19.0	**34.2**	1.33	1.22	0.89	**1.15**
T_6 (10 x 7.5)	133.3	8.82	5.85	6.18	**6.95**	34.7	42.0	22.4	**33.0**	1.89	1.33	1.22	**1.48**
T_7 (10x 5)	200.0	8.81	6.37	6.41	**7.20**	33.7	39.6	15.1	**29.5**	2.56	1.89	1.56	**2.00**
Mean		**7.37**	**5.83**	**6.22**		**67.0**	**85.9**	**29.2**		**0.97**	**0.73**	**0.56**	
Factors		SEm±	C.D @t 5%			SEm±	CD @ 5 %			SEm±	CD @ 5 %		
Treatments		0.20	0.58			3.1	9.0			0.09	0.26		
Genotypes		0.13	0.38			2.0	5.8			0.06	0.16		
Interaction		0.35	1.01			5.4	15.5			0.15	NS		
C.V. (5%)		9.4				15.5				35.8			

Table.4 Effect of plant densities on photosynthetic rate and productive tillers in finger millet genotypes

Spacing (cm x cm) / Varieties	Plant density (No. m^{-2})	Photosynthetic rate (u Mol $m^{-2}s^{-1}$)				Productive tillers (No. m^{-2})				Productive tillers (No. $hill^{-1}$)			
		GE-292	GE-199	GPU-28	Mean	GE-292	GE-199	GPU-28	Mean	GE-292	GE-199	GPU-28	Mean
T_1 (30 x 15)	22.2	19.67	17.63	19.33	**18.88**	100. 7	88.3	100.0	**96.3**	4.53	3.98	4.50	**4.34**
T_2 (30 x 10)	33.3	18.73	20.27	18.53	**19.18**	111. 7	105.0	102.7	106.4	335	3.15	3.08	**3.20**
T_3 (22.5 x 10)	44.4	16.47	20.30	18.73	**18.50**	127. 0	137.7	119.7	**128.1**	2.86	3.10	2.70	**2.89**
T_4 (15 x 10)	66.7	15.93	18.37	18.73	**17.68**	213.4	183.7	175.6	**190.9**	3.20	2.76	2.63	**2.86**
T_5 (10 x 10)	100.0	16.53	20.67	17.57	**18.26**	229.0	190.0	199.0	**206.0**	2.29	1.90	2.00	**2.06**
T_6 (10 x 7.5)	133.3	13.30	19.10	13.63	**15.34**	233.7	196.9	219.8	**216.8**	1.76	1.48	1.65	**1.62**
T_7 (10x 5)	200.0	19.40	19.67	12.50	**17.19**	244.3	216.2	248.5	**236.3**	1.22	1.08	1.24	**1.18**
Mean		17.15	19.43	17.01		**180.0**	**159.7**	**166.5**		**2.75**	**2.49**	**2.54**	
Factors		SEm±	CD @ 5 %			SEm±	CD @ 5 %			SEm±	CD @ 5 %		
Treatments		1.43	NS			4.9	14.1			0.066	0.19		
Genotypes		0.94	NS			3.2	9.2			0.043	0.12		
Interaction		2.48	NS			8.5	24.4			0.115	0.33		
C.V (5%)		24.2				8.7				7.72			

Table.5 Effect of plant densities on mean ear weight, test weight and spikelet fertility in finger millet genotypes

Spacing (cm x cm) / Varieties	Plants (No. m^{-2})	Mean ear weight (g)				Test weight (g/ 1000 seeds)				Spikelet fertility (%)			
		GE-292	GE-199	GPU-28	Mean	GE-292	GE-199	GPU-28	Mean	GE-292	GE-199	GPU-28	Mean
T_1 (30 x 15)	22.2	6.95	8.89	8.30	**8.05**	3.29	3.10	4.05	**3.48**	80.8	86.8	75.7	**81.1**
T_2 (30 x 10)	33.3	6.92	7.61	7.10	**7.21**	3.25	3.12	4.11	**3.49**	82.1	76.6	74.9	**77.8**
T_3 (22.5 x 10)	44.4	6.83	7.21	7.20	**7.08**	3.27	2.99	3.86	**3.37**	77.0	93.0	73.6	**81.2**
T_4 (15 x 10)	66.7	4.56	5.28	5.07	**4.97**	3.10	3.20	3.71	**3.34**	74.4	80.6	78.4	**77.8**
T_5 (10 x 10)	100.0	3.62	4.80	4.20	**4.21**	3.08	3.28	3.68	**3.35**	64.4	76.8	75.9	**72. 4**
T_6 (10 x 7.5)	133.3	3.94	4.27	4.10	**4.11**	3.05	2.97	3.84	**3.29**	74.5	87.0	75.5	**79.0**
T_7 (10x 5)	200.0	3.74	4.17	3.75	**3.89**	3.07	2.99	3.82	**3.29**	64.3	81.5	65.1	**70.3**
Mean		**5.23**	**6.04**	**5.67**		**3.16**	**3.09**	**3.87**		**73.9**	**83.2**	**74.1**	
Factors		SEm±	C.D @t 5%			SEm±	CD @ 5 %			SEm±	CD @ 5 %		
Treatments		0.22	0.63			0.054	0.155			1.77	5.1		
Genotypes		0.14	0.41			0.035	0.101			1.16	3.31		
Interaction		0.38	NS			0.094	NS			3.07	8.8		
C.V (5%)		11.6				4.8				6.89			

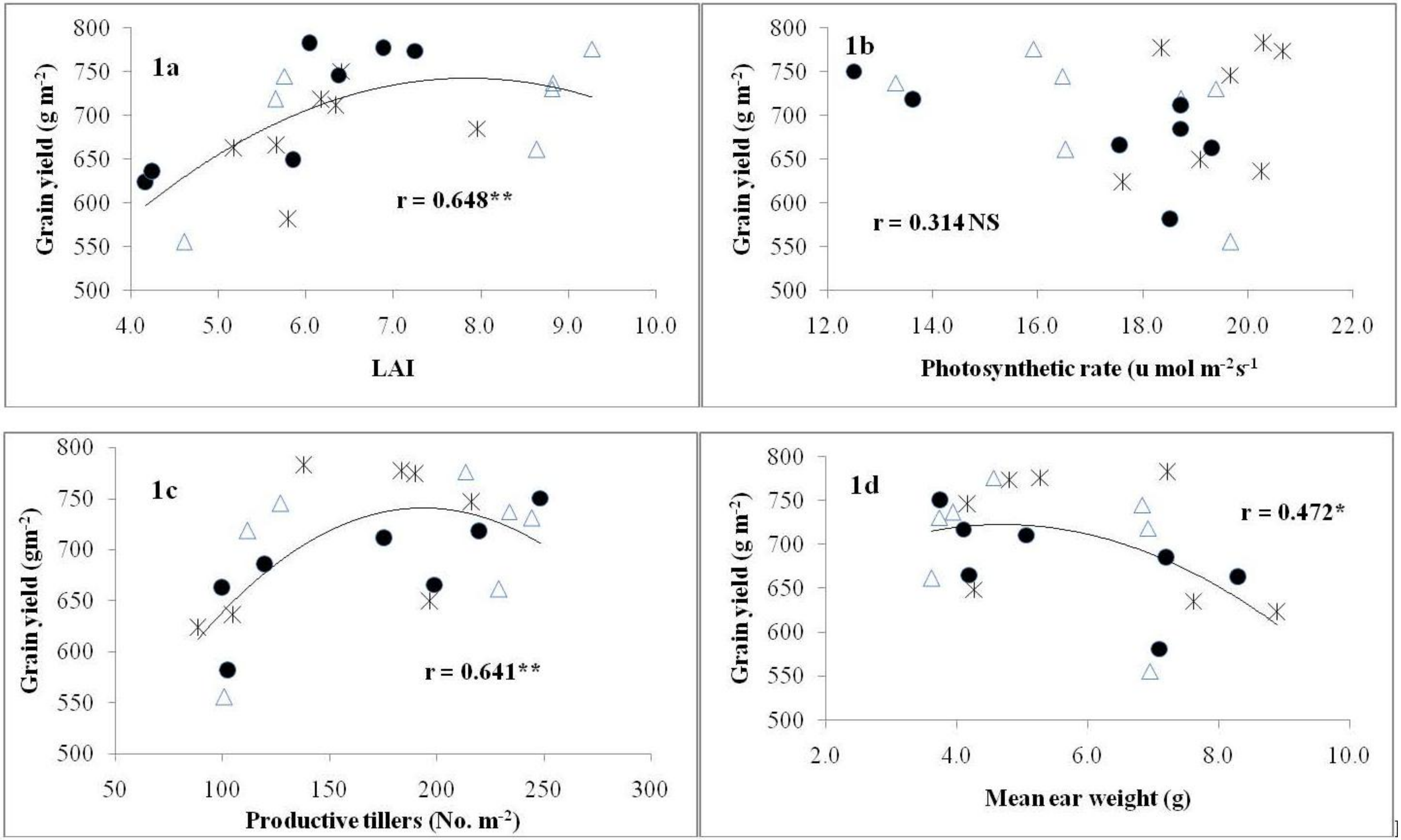

Fig.1 Relationship between source size, yield parameters and grain yield in finger millet genotypes
(* = GE-199, Δ = GE-292, ●=GPU-28)

The wider spacing also reduce the productive tiller number per unit land area significantly and thus decreased grain yield (Table 4 and Anitha, 2015; Nigus and Melese, 2018). The results reiterate that the source is not a major limitation under optimal irrigation conditions in finger millet.

Another important trait that determines the biomass production and grain yield is the source activity (photosynthetic rate). The photosynthetic rate did not differ significantly between the planting densities or varieties (Table 4). Photosynthetic rate was not related significantly to biomass and grain yield (Table 2 and Fig. 1b). The finger millet being C_4 (NAD-ME) species (Ueno *et al.*, 2006) has higher photosynthetic rate and thus the photosynthetic rate is not a limitation, rather light interception by the lower leaves at narrow spacing is a major constraint. Therefore, possible suggestions for yield improvement under optimal irrigation conditions could be through selection and breeding for leaf acute angle to result in higher light use efficiency as source is not a limitation.

The study show that, the source size (LAI) and source activity (photosynthetic rate) in finger millet (GPU-28) is not a limitation under optimal input conditions, but the sink parameters such as productive tillers or ear size could be the limitations for higher productivity (Bezaweletaw *et al.*, 2006; Assefa *et al.*, 2013; Dineshkumar *et al.*, 2014; Maobe *et al.*, 2014; Jadhav *et al.*, 2015; Madhavilatha and Subbarao, 2015; Simbagije, 2016). The productive tillers m^{-2} (sink number) was significantly increased with increased plant density from 44.4 m^{-2} and above (Table 4) but the grain yield was not increased significantly although the relationship between productive tillers and grain yield was significantly positive (Table 2; Fig. 1c). In contrast, a negative correlation between the tiller number and grain yield has been reported due to significant decrease in ear size (Jyothsna *et al.*, 2016). The mean ear weight (sink size) was related to grain yield positively and significantly (Fig. 1d) but beyond 5 g ear^{-1}, the yield was in declining trend, this clearly suggests the compensation mechanism between tiller number and ear size (r = 0.998**, Table 2 and 5). In addition, increased plant density above 33.3 m^{-2} decreased the test weight (Table 5). With respect to spikelet fertility, although particular trend is not observed, at closer spacing (high plant density), the spikelet fertility was markedly low (Table 5).

Increase in tiller number per unit land area (above 44.4 hills m^{-2}) by reduced spacing, will lead to management problems like weed management and disease management (Bitew and Asargew, 2014) with no significant increase in grain yield. Therefore spacing of 22.5 cm x 10 cm could be optimum. Other research reports also show that 25 cm x 25 cm over the 10 cm x 10 cm (Bhatta *et al.*, 2017) and 20 cm between the rows as over the 10 cm gave better grain yields (Shinggu and Gani, 2012).

At the spacing of 22.5 cm x 10 cm, increase in productive tiller number or ear size can increase the grain yield as source is not a constraint in finger millet. In this direction, Kalpana *et al.*, (2016) reported that at a given spacing, increase in tiller number per hill up to 4.9 increased the grain yield of finger millet. Therefore, further improvement in grain yield of finger millet could be possible by (i) increased productive tillers per hill to five at the spacing of 22.5 cm x 10 cm or 30 cm x 7.5 cm by management practices (Damar *et al.*, 2016), (ii) identifying genotypes with erect leaves to intercept more sunlight, (iii) removal of old leaves which acts as sink during reproductive phase and planting two seedlings per hill.

Acknowledgments

Authors thank Dr. S. Ramesh, Professor, Department of Plant Breeding & Genetics, Dr. H.M. Jayadeva, Professor, Department of Agronomy for their suggestions and support to conduct the experiment.

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How to cite this article:

Mujahid Anjum, Y. A. Nanja Reddy and Sheshshayee. M. S. 2020. Optimum LAI for Yield Maximisation of Finger Millet under Irrigated Conditions. *Int.J.Curr.Microbiol.App.Sci.* 9(05): 1535-1547. doi: https://doi.org/10.20546/ijcmas.2020.905.174