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Finger millet and horsegram intercropping systems in replacement series for advantages and weed smothering

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ABSTRACT

The land use efficiency and weed suppression through intercropping plays a pivotal role. A field experiment was carried out on finger millet (*Eleusine indica* L. Gaertn) –horsegram (*Macrotyloma uniflorum* (Lam.) Verdc.) mono- and intercropping with various weeding (0, 1, or 2 hand-weeding operations) and row spacing (20 and 30 cm) treatments in the Bastar plateau region of India over consecutive five *Kharif* seasons (2010/2014). The experimental design was a randomized complete block with eighteen treatments replicated thrice. Five percent significant differences were observed in yield and its economics with and without weeding treatments. Horsegram yield was significantly reduced by Finger millet when intercropped. However, total productivity and land use efficiency were higher under the intercropping system as compared to monocrops of either species. There was a significant reduction in weed density and biomass for the intercropping system over both monocrops. Finger millet facilitated an increase in nodule number and dry weight in horsegram under intercropping over monocrops, moreover, root length of horsegram was greater when intercropped. These findings suggest that intercropping Finger millet and horsegram increase total productivity per unit area improve land use efficiency and suppress weeds. Focussing the experimental findings, Finger millet–horsegram (30 cm) with two weedings may be recommended for yield advantage, higher net income, more efficient utilization of resources, and weed suppression as a biological control in western plateau region of India.

Key words: Additive series, Finger millet- horsegram monocropping, Finger millet–horsegram intercropping, Inter-specific competition, , Weed smothering.

INTRODUCTION

Finger millet (*Eleusine indica* L. Gaertn), the most important cereal in the dry and rainfed region of world, and horsegram (*Macrotyloma uniflorum* (Lam.) Verdc.), the third most important pulse crop play a vital role in rainfed agricultural economy (FAO, 2003). In the Basar plateau region of India, the most commonly grown *kharif* cereal and pulse crops are also Finger millet and horsegram; however, because the whimsical nature of weather and degraded soil configuration offer little opportunity for stable agricultural production, monocropping can not ensure stability of production (Banik *et al.,* 2000). Again, at adequate density, the yield of uniformly distributed crop plants can be optimised by suppressing weeds (Johri *et al.,* 1992; Weiner *et al.,* 2001) and deploying nutrients (Midya *et al.,* 2005; Scott *et al.,* 1987). It is generally accepted that yield increases when Finger millet rows are narrowly spaced. This, however, is not always supported by the literature (Crabtree and Rupp, 1980; Teich *et al.,* 1993; McLeod *et al.,* 1996; Lafond and Gan, 1999; Hiltbrunner *et al.,* 2004). Intercropping has gained interest because of potential advantages it offers over yielding, i.e. improved utilization of growth resources by the crops and improved reliability from season to season. When a legume is grown in association with another crop (intercropping), commonly a cereal, the nitrogen nutrition of the associated crop may be improved by direct nitrogen transfer from the legume to cereal (Giller and Wilson, 1991). Legumes, with their adaptability to different cropping patterns and their ability to fix nitrogen, may offer opportunities to sustain increased productivity (Jeyabal and Kuppuswamy, 2001). Therefore, productivity normally is potentially enhanced by the inclusion of a legume in a cropping system (Maingi *et al.,* 2001). Legume intercrops are also potential sources of plant nutrients that complement/ supplement inorganic fertilizers (Banik and Bagchi, 1994; Ofori and Stern, 1987). In addition, legume intercrops are included in cropping systems because they reduce soil erosion (Giller and Cadisch, 1995) and suppress weeds (Exner and Cruse, 1993). Adverse environmental conditions under Bastar plateau (Banik *et al.,* 2006), which is detrimental to their crops, may be congenial for weeds, the menacing pest in crop production. Use of herbicides in any crop mixture is a risky endeavour and not an eco-friendly approach. Biological, and cultural weed control are important components of Integrated Weed Management. Of late, researchers are confronted with the complex problem of weed

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management on rainfed cultivation by ecological means, giving due consideration to minimal use of chemicals with least disturbance to the environment. Weed management in intercropping, however, has hardly been studied to date (Altieri and Liebman, 1986; Moody and Shetty, 1979; Midya *et al.,* 2005). Very little research attention has been given to ecological weed management using crop mixtures in Kharif crops in the Bastar plateau area. The major objective of this study was therefore, to investigate the Finger millet–horsegram intercropping as a ecological weed control measure in the sub-tropical, uplands of the plateau region of India. Another objective of the study was also to examine the complementarity of the intercropping system root penetration depth and nodulation pattern of horsegram as influenced with the association of finger millet and complex crop–weed interaction under the intercropping system.

MATERIALS AND METHODS

Experimental site: The experiments were conducted at Instructional farm, S.G. College of Agriculture & Research Station, Jagdalpur, India (19°06N; 82°57E; elev. 450.5 m) in the Bastar plateau region of India. Initial soil samples were collected using a soil sampler to a 15–20 cm depth. Organic carbon and available N, P and K were analyzed adapting a method outlined by Jackson (1973). The soil of the study area was well-drained sandy loam (Alfisol) with a pH of 6.5 (1:2 soil and water suspension), electrical conductivity 0.25 dSm^{-1} (1:2 soil and water suspension) and organic carbon level of 0.30% and available low in available N (242 kg/ha), medium in available P (13.6kg/ha) and high in K (250 kg/ha), respectively.

Field experiments and experimental design: Experiments were conducted during the Kharif seasons of five consecutive years (2010-2014). Each experiment had 18 treatments arrangement with three replications in a randomized complete block design. Finger millet and horsegram were grown as monocrops or intercropped in 2:1 ratio. Row spacing treatments were 20 to 30 cm rows, each with or within-row seed space of 10-cm, and there were three hand-weeding treatments (unweeded, one weeding, or two weedings). Each plot was 5m×3m.

Cultural practices: Soil manipulation was carried out by tractor ploughing followed by harrowing. The fertilizer schedule was 50:50:20 kg N, P_2O_5 and K_2O ha^{-1} for monocropped and intercropped Finger millet 20:10:10 (N, P_2O_5 and K_2O ha^{-1}). Proportionate fertilizers were also applied to intercropped horsegram along the rows. Two-thirds of nitrogen in the form of urea (46-0-0) and the whole amount of P_2O_5 and K_2O in the form of single super phosphate (0-16-0) and muriate of potash (0-0-60) respectively, were applied as basal and remaining one-third nitrogen was top dressed 25 days after sowing (DAS) at 5 leaf stage of Finger millet. The total amount of N, P_2O_5 and K_2O in the form of urea, SSP and MOP was applied as basal in horsegram. Recommended agronomic package of practices was followed (Pradhan *et al.,* 2011). Weeding operations were accomplished at 25 and 40 DAS depending on the weeding treatments. Dry seeding was taken place on 20, 22, 21, 25 and 28 June, 2010 to 2014, respectively. Finger millet was harvested on 22, 23, 20, 26 and 30 October, 2010 to 2014, respectively, and horsegram was harvested on 23, 22, 20, 25 and 27, 2010 to 2014, respectively. Harvesting was done manually with the help of sickles leaving border rows (two rows from each side).

Observations and data analysis: Five horsegram plants from each horsegram monocrop and intercrop plot were dug up at 45 days after emergence (before flowering, which occurred approximately 50 DAS). Nodules were removed from roots and counted and dry matter was measured (Ghosh, 2004). Length and dry weight of roots were also recorded. Major weeds infesting the crops were identified and data pertaining to weed population and dry matter were recorded prior to harvest. For dry weight determination, the samples were oven-dried at 70°C temperature to a constant weight. Land equivalent ratio was calculated as follows (Willey, 1979):

$$LER = (LERa + LERb) = \frac{(Yab)}{(Yaa)} + \frac{(Yab)}{(Yaa)}$$

where LERa and LERb are the partial LER of crop finger millet and horsegram, respectively. Competitive ratio was calculated by following the formula as advocated by Willey and Rao (1980):

$$CR = CEa + CRb \quad CRa = \frac{(LERa)}{(LERb)} \times \frac{(Zba)}{(Zab)}$$

Where CRa is the competitive ratio for intercrop Finger millet.

Relative crowding coefficient (*K*) was calculated following the formula (DeWit, 1960):

$$K = Kab \times Kba = \left[\frac{(Yab \times Zba)}{(Yaa - Yab \times Zab)}\right] \chi \left[\frac{(Yba \times Zab)}{(Ybb\ Yba \times Zba)}\right]$$

Where Kab and Kba are relative crowding coefficient for Finger millet and horsegram intercrop, respectively,

Aggressivity (Yab) was calculated (McGilchrist, 1965) as:

$$Yab = \left[\frac{(Yab)}{(Yaa \times Zab)}\right] \chi \left[\frac{(Yba)}{(Ybb \times Zba)}\right]$$

Where Yab is the aggressivity of intercrop Finger millet, whereas, Finger millet equivalent yield was calculated (Chetty and Reddy, 1987) as, Finger millet equivalent yield =Yield of Horsegram×(Price of Horsegram/Price of Finger millet), and Actual yield loss (Banik, 1996) was calculated as:

$$AYL = AYLa + AYLb = \left[\frac{(Yba/Zab)}{(Yaa/Zaa)} - 1\right] + \left[\frac{(Yba/Zba)}{(Yaa/Zab)}\right]$$

Where AYLa and AYLb are the partial yield loss of intercrop Finger millet and horsegram, respectively.

Yab representing the yield of intercrop a (Finger millet) in combination with b (horsegram), Yba the yield of intercrop b (horsegram) in combination with a (Finger millet). Zab representing the sown proportion of intercrop a (Finger millet) in combination with b (horsegram) and Zba the sown proportion of intercrop b (horsegram) in combination with a (Finger millet). Data were analyzed using the Analysis of Variance (ANOVA) technique following normal procedure (Gomez and Gomez, 1984). Combined analyses were done to identify the temporal effect on the treatments as given by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Grain and seed yield: Mean grain yield of Finger millet and horsegram (Table 1) was higher in monocrops as compared to intercrops. Highest mean Finger millet grain yield (24.48 q ha^{-1}) was obtained under monocrop finger millet at 20 cm spacing weeded twice (Table 1). Highest seed yield of horsegram (9.81q ha^{-1}) was recorded under monocropping at 20 cm spacing weeded twice. Among intercropping systems, highest mean grain yield of Finger millet (18.02 q ha^{-1}) was obtained at 20 cm spacing with two weedings, whereas highest horsegram yield (8.87 q ha^{-1}) was registered when Finger millet–horsegram (20 cm) was weeded twice. Uncontrolled weeds caused severe reduction in grain yield for both crop species. Monocropping produced lowest grain yield of unweeded Finger millet at 30 cm spacing (15.42 q ha^{-1}) and unweeded monocrop horsegram at 30 cm spacing (4.04 q ha^{-1}). There was 37.01% reduction in grain yield of unweeded monocroped Finger millet when grown at 20 cm spacing as compared to when monocropped Finger millet was sown at same spacing and weeded twice. The reduction in grain yield of Finger millet was 30.41% when intercropped with horsegram at 20 cm spacing without weeding. Whereas 18.81% grain yield depression was noted under Finger millet–horsegram at 20 cm spacing with two hand-weedings. There was 42.08% reduction in grain yield under unweeded monocropped horsegram at 30 cm spacing as compared to the treatment where monocropped horsegram at same spacing weeded twice.

Relative yield loss and competition functions: The land equivalent ratio value for all the intercropped treatments was

Table1: Grain yield (q ha^{-1}) of finger millet and chickpea as affected by row spacing, weeding management and intercropping system (data are the means of three replications).

Treatment	2010		2011		2012		2013		2014		Mean	
	FM	HG	FM	HG	FM	HG	FM	HG	FM	HG	FM	HG
T1	20.12	0.00	16.50	0.00	16.83	0.00	22.53	0.00	19.60	0.00	19.12	
T2	16.23	0.00	13.31	0.00	13.57	0.00	18.18	0.00	15.81	0.00	15.42	
T3	23.45	0.00	19.23	0.00	19.61	0.00	26.26	0.00	22.85	0.00	22.28	
T4	20.32	0.00	16.66	0.00	17.00	0.00	22.76	0.00	19.80	0.00	19.31	
T5	25.76	0.00	21.12	0.00	21.55	0.00	28.85	0.00	25.10	0.00	24.48	
T6	22.34	0.00	18.32	0.00	18.69	0.00	25.02	0.00	21.77	0.00	21.23	
T7	0.00	5.34	0.00	4.38	0.00	4.47	0.00	5.98	0.00	5.20		5.07
T8	0.00	4.25	0.00	3.49	0.00	3.55	0.00	4.76	0.00	4.14		4.04
T9	0.00	6.45	0.00	5.29	0.00	5.39	0.00	7.22	0.00	6.28		6.13
T10	0.00	8.31	0.00	6.81	0.00	6.95	0.00	9.31	0.00	8.10		7.90
T11	0.00	10.32	0.00	8.46	0.00	8.63	0.00	11.56	0.00	10.06		9.81
T12	0.00	7.89	0.00	6.47	0.00	6.60	0.00	8.84	0.00	7.69		7.50
T13	15.40	3.45	12.63	2.83	12.88	2.89	17.25	3.86	15.01	3.36	14.63	3.28
T14	13.20	3.04	10.82	2.49	11.04	2.54	14.78	3.40	12.86	2.96	12.54	2.89
T15	16.40	4.67	13.45	3.83	13.72	3.91	18.37	5.23	15.98	4.55	15.58	4.44
T16	15.67	6.23	12.85	5.11	13.11	5.21	17.55	6.98	15.27	6.07	14.89	5.92
T17	18.97	7.54	15.56	6.18	15.87	6.31	21.25	8.44	18.48	7.35	18.02	7.16
T18	16.07	5.25	13.18	4.31	13.44	4.39	18.00	5.88	15.66	5.12	15.27	4.99
S.E. (±)	**1.00**	**1.12**	**0.82**	**0.92**	**0.84**	**0.93**	**1.12**	**1.25**	**0.97**	**1.09**	**0.95**	**1.06**
LSD (P=0.05)	**2.57**	**2.87**	**2.11**	**2.35**	**2.15**	**2.40**	**2.88**	**3.21**	**2.50**	**2.80**	**2.44**	**2.72**

T1: Mono cropping finger millet at 20 cm spacing without hand hoeing, T2:Mono cropping finger millet at 30 cm spacing without hand hoeing, T3: Mono cropping finger millet at 20 cm spacing with one hand hoeing, T4: Mono cropping finger millet at 30 cm spacing with one hand hoeing, T5: Mono cropping finger millet at 20 cm spacing with two hand hoeing, T6: Mono cropping finger millet at 30 cm spacing with two hand hoeing, T7: Monocrop horse gram at 20 cm spacing without hand hoeing, T8: Monocrop horse gram at 30 cm spacing without hand hoeing, T9: Monocrop horse gram at 20 cm spacing with one-hand hoeing, T10: Monocrop horse gram at 30 cm spacing with one-hand hoeing, T11: Monocrop horse gram at 20 cm spacing with two-hand hoeing, T12: Monocrop horse gram at 30 cm spacing with two-hand hoeing, T13: Finger millet–horse gram at 20 cm spacing without hand hoeing, T14: Finger millet–horse gram at 30 cm spacing without hand hoeing, T15: Finger millet–horse gram at 20 cm spacing with one-hand hoeing, T16: Finger millet–horse gram at 30 cm spacing with one-hand hoeing, T17: Finger millet–horse gram at 20 cm spacing with two-hand hoeing, T18: Finger millet–horse gram at 30 cm spacing with two-hand hoeing.

greater than unity. Maximum land equivalent ratio (1.52) was recorded under Finger millet–horsegram (30 cm) weeded once followed by Finger millet–horsegram (20 cm) weeded twice (1.47). Intercropped Finger millet had always greater competitive ratio as compared to intercropped horsegram. Positive aggressivity values for Finger millet (1.11–1.27) also were recorded under intercropping systems. Relative crowding coefficient values for Finger millet were greater than two, whereas, it was less for horsegram except in case of horsegram under Finger millet–horsegram (20 cm) with the one weeding treatment. Kab values were numerically higher than Kba values. The products of relative crowding coefficient values (*K*) which were always more than one, maximum value was recorded under Finger millet–horsegram (30 cm spacing) when without weeding. Minimum relative yield loss (8.55%) and maximum relative yield loss (19.88%) for Finger millet was observed under Finger millet–horsegram at 30-cm spacing with one hand-weeding and unweeded Finger millet–horsegram at 20-cm spacing, respectively. Whereas, in case of horsegram, minimum and maximum values were recorded under unweeded Finger millet–horsegram (30-cm) spacing and Finger millet–horsegram (20-cm) spacing weeded twice, respectively. The mean data of partial Actual Yield Loss (AYL) of Finger millet and horsegram were negative indicating yield loss due to intercropping when per plant yield was considered. Maximum actual yield loss value was observed (-0.726) under Finger millet–horsegram at 20 cm spacing with two weedings.

Numbers and dry weight of nodules: Nodule numbers increased with increasing row spacing from 20 to 30 cm (Table 2). Significantly higher nodule numbers were registered for weeded monocrops, irrespective of row spacing (Table 2). However, in intercropping treatments, the variation between unweeded and both weeding treatments was not significant. Under intercropping treatments higher nodule numbers were produced as compared to monocropped horsegram (Table 2). Among the intercropping treatments, highest number of nodules (32.01) in horsegram was recorded in Finger millet–horsegram at 30 cm spacing weeded twice. Dry weight of nodules also followed the same trends (Table 2).

Depth of penetration of roots and dry weight of roots: There was no significant effect of spacing on depth of penetration of roots. Root length was shortest under unweeded monocropped horsegram sown at 20 cm spacing (Table 2). Root length increased as the number of weeding operation increased. Additionally, root length was higher under intercropping as compared to monocrops. The longest roots were recorded under the intercropping system of Finger millet–horsegram (30 cm) weeded twice Average number and weight of nodules per plant (g), root weight per plant (g) and root length (cm) of horsegram as affected by different treatments (mean of 5 years and three replicates).

Effect on weed flora, density and biomass: The major weed flora of the experimental site comprised of grassy weeds: *Setaria glauca, Dicanthium annulatum, Digitaria sanguinalis* and *Eragrostis pilosa*; Sedge: *Cyperus iria*; and

Table 2: Average number and weight of nodules per plant (g), root weight per plant (g) and root length (cm) of chickpea as affected by different treatments (means of 5years and three replicates).

	Treament	Nodules	Weight nodule	Root length	Dry wt root
T7	Monocrop horse gram at 20 cm spacing without hand hoeing.	7.69	0.361	12.72	0.573
T8	Monocrop horse gram at 30 cm spacing without hand hoeing.	10.60	0.498	17.54	0.789
T9	Monocrop horse gram at 20 cm spacing with one-hand hoeing.	12.34	0.580	20.42	0.919
T10	Monocrop horse gram at 30 cm spacing with one-hand hoeing	16.78	0.789	27.76	1.249
T11	Monocrop horse gram at 20 cm spacing with two-hand hoeing	21.45	1.008	35.49	1.597
T12	Monocrop horse gram at 30 cm spacing with two-hand hoeing	27.45	1.290	45.42	2.044
T13	Finger millet–horse gram at 20 cm spacing without hand hoeing	12.25	0.576	20.27	0.912
T14	Finger millet–horse gram at 30 cm spacing without hand hoeing	15.16	0.713	25.08	1.129
T15	Finger millet–horse gram at 20 cm spacing with one-hand hoeing	16.90	0.794	27.96	1.258
T16	Finger millet–horse gram at 30 cm spacing with one-hand hoeing	21.34	1.003	35.31	1.589
T17	Finger millet–horse gram at 20 cm spacing with two-hand hoeing	26.01	1.222	43.03	1.937
T18	Finger millet–horse gram at 30 cm spacing with two-hand hoeing	32.01	1.504	52.96	2.383
	S.E. (±)	**1.78**	**0.08**	**2.94**	**0.13**
	LSD (P=0.05)	**4.56**	**0.21**	**7.54**	**0.34**

T7: Monocrop horse gram at 20 cm spacing without hand hoeing, T8: Monocrop horse gram at 30 cm spacing without hand hoeing, T9: Monocrop horse gram at 20 cm spacing with one-hand hoeing, T10: Monocrop horse gram at 30 cm spacing with one-hand hoeing, T11: Monocrop horse gram at 20 cm spacing with two-hand hoeing, T12: Monocrop horse gram at 30 cm spacing with two-hand hoeing, T13: Finger millet–horse gram at 20 cm spacing without hand hoeing, T14: Finger millet–horse gram at 30 cm spacing without hand hoeing, T15: Finger millet–horse gram at 20 cm spacing with one-hand hoeing, T16: Finger millet–horse gram at 30 cm spacing with one-hand hoeing, T17: Finger millet–horse gram at 20 cm spacing with two-hand hoeing, T18: Finger millet–horse gram at 30 cm spacing with two-hand hoeing.

Table 3: Economics of finger millet – horsegram intercropping systems (mean of 5 years and three replicates).

	Treatment	FMEY	COC	GMR	NMR
T1	Mono cropping finger millet at 20 cm spacing without hand hoeing	19.12	72.67	555.73	483.06
T2	Mono cropping finger millet at 30 cm spacing without hand hoeing	15.42	65.41	448.29	382.88
T3	Mono cropping finger millet at 20 cm spacing with one hand hoeing	22.28	87.21	647.71	560.50
T4	Mono cropping finger millet at 30 cm spacing with one hand hoeing	19.31	79.94	561.26	481.32
T5	Mono cropping finger millet at 20 cm spacing with two hand hoeing	24.48	94.48	711.52	617.04
T6	Mono cropping finger millet at 30 cm spacing with two hand hoeing	21.23	101.74	617.05	515.31
T7	Monocrop horse gram at 20 cm spacing without hand hoeing.	5.07	58.14	147.50	89.36
T8	Monocrop horse gram at 30 cm spacing without hand hoeing.	4.04	52.33	117.39	65.06
T9	Monocrop horse gram at 20 cm spacing with one-hand hoeing.	6.13	69.77	178.16	108.39
T10	Monocrop horse gram at 30 cm spacing with one-hand hoeing	7.90	63.95	229.53	165.58
T11	Monocrop horse gram at 20 cm spacing with two-hand hoeing	9.81	75.58	285.05	209.47
T12	Monocrop horse gram at 30 cm spacing with two-hand hoeing	7.50	81.40	217.93	136.53
T13	Finger millet–horse gram at 20 cm spacing without hand hoeing	13.87	101.74	403.24	301.50
T14	Finger millet–horse gram at 30 cm spacing without hand hoeing	11.92	91.57	346.54	254.97
T15	Finger millet–horse gram at 20 cm spacing with one-hand hoeing	18.99	122.09	551.96	429.87
T16	Finger millet–horse gram at 30 cm spacing with one-hand hoeing	25.13	111.92	730.38	618.46
T17	Finger millet–horse gram at 20 cm spacing with two-hand hoeing	31.53	132.27	916.61	784.34
T18	Finger millet–horse gram at 30 cm spacing with two-hand hoeing	21.27	142.44	618.24	475.80
S.E. (±)	**2.32**	**7.36**	**67.38**	**60.01**	
LSD (P=0.05)	**6.40**	**20.35**	**186.23**	**165.88**	

*** Value calculated in Euro**

T1: Mono cropping finger millet at 20 cm spacing without hand hoeing, T2:Mono cropping finger millet at 30 cm spacing without hand hoeing, T3: Mono cropping finger millet at 20 cm spacing with one hand hoeing, T4: Mono cropping finger millet at 30 cm spacing with one hand hoeing, T5: Mono cropping finger millet at 20 cm spacing with two hand hoeing, T6: Mono cropping finger millet at 30 cm spacing with two hand hoeing, T7: Monocrop horse gram at 20 cm spacing without hand hoeing, T8: Monocrop horse gram at 30 cm spacing without hand hoeing, T9: Monocrop horse gram at 20 cm spacing with one-hand hoeing, T10: Monocrop horse gram at 30 cm spacing with one-hand hoeing, T11: Monocrop horse gram at 20 cm spacing with two-hand hoeing, T12: Monocrop horse gram at 30 cm spacing with two-hand hoeing, T13: Finger millet–horse gram at 20 cm spacing without hand hoeing, T14: Finger millet–horse gram at 30 cm spacing without hand hoeing, T15: Finger millet–horse gram at 20 cm spacing with one-hand hoeing, T16: Finger millet–horse gram at 30 cm spacing with one-hand hoeing, T17: Finger millet–horse gram at 20 cm spacing with two-hand hoeing, T18: Finger millet–horse gram at 30 cm spacing with two-hand hoeing.

broad leaf weeds: *Celosia argentia*, *Spilanthes acmella*, *Ageratum conyzoides*, *Blainvillea acmella* and *Spermococe hispida*. The proportion of broadleaf weeds was greater than grassy weeds. Maximum dry matter of weeds (186.5 gm^{-2}) and highest weed population (220 gm^{-2}) was recorded under the unweeded Finger millet monocrop (20 cm). Monocropped horsegram had significantly less weed population and dry matter as compared to monocropped Finger millet. Intercropping system significantly reduced the weed population and biomass as compared to the monocropping. There was significant reduction of weed population and weed biomass under intercropping system of unweeded Finger millet–horsegram at both row spacing as compared to monocropping of Finger millet with one weeding treatment, but comparable with sole horsegram weeded once. There was 69.7% reduction in weed biomass and 70% in weed population under the intercropping treatment of Finger millet–horsegram at 20 cm spacing without weeding treatment as compared to unweeded monocrop Finger millet at 20 cm spacing; whereas, the corresponding values were 34.6 and 38%, respectively, for unweeded monocropped horsegram at 20 cm spacing. The reduction of weed biomass and density under Finger millet sown at 20 cm spacing with one weeding and two weedings was 45.2, 44.7 and 72.7, 73.1%, respectively; whereas, in the case of monocropped horsegram with 20-cm row spacing the reduction in weed biomass and weed density was 25, 42.4 and 66.7, 71.7%, respectively. On the contrary, unweeded Finger millet–horsegram intercrop (20-cm) reduced weed biomass 44.8% as compared to Finger millet at 20 cm spacing weeded once. So, the unweeded intercropping treatment was found to be superior over one weeding treatment for weed control in Finger millet. Narrow row spacing (20-cm) in all the treatments was found to be effective as wide spacing (30-cm), whether intercropped or monocropped. Intercropping treatments where weeding was done registered lower weed populations and dry matter.

Economic feasibility: Finger millet equivalent yield (Table 3) was significantly higher ($P = 0.05$) when intercropped as compared to respective monocrops. Highest Finger millet equivalent yield (31.53 q ha^{-1}) was achieved under Finger millet–horsegram (20 cm) weeded twice. Unweeded intercropping treatments also recorded significantly higher ($P = 0.05$) Finger millet-equivalent yield as compared to

unweeded monocropped Finger millet sown at 20 cm or horsegram sown at 30 cm spacing (Table 3). Monetary advantages of all the intercropping systems were positive clearly indicating the yield advantages of intercropping over monocropping (Table 3). Significantly higher gross return (Euro 96.61 ha^{-1}) was achieved under Finger millet–horsegram (20 cm) weeded twice. Lowest net return of (Euro 117.39 ha^{-1}) was obtained under unweeded monocropped horsegram (20 cm) (Table 3). There were significant differences in net returns with weeding treatments and no weeding treatments, irrespective of species. Finger millet–horsegram (30 cm) with no weeding treatment secured significantly higher net return over unweeded monocropped Finger millet at both row spacing, monocropped Finger millet at 30 cm spacing weeded once, and horsegram monocrops, the 30 cm spacing weeded twice (Table 3). All weeded intercrop treatments registered significantly higher net returns over other treatments. Finger millet–horsegram (20 cm) weeded twice recorded significantly higher net return over other weeded intercropping treatments, which were not different from each other. Highest gross return (Euro 916.61ha^{-1}) and net return (Euro 784.34 ha^{-1}) were secured by Finger millet–horsegram (20 cm) weeded twice. Unweeded monocrops recorded the least return (Table 3).

Yield and yield equivalent: Higher grain yield of monocropped Finger millet and horsegram relative to intercropping treatments may be due to the fewer disturbances in the habitat in homogeneous environment of monocropping systems (Grime, 1977). Fluctuations in weather parameters affected the grain yield over years. Stiff competition by the weeds resulted less grain yield under the unweeded treatment. Higher Finger millet-equivalent yield when intercropped compared to respective monocrops was due to higher total productivity because intercropping exploited resources more efficiently (Midya *et al.,* 2005). It may be due to the legume affect of horsegram on nitrogen nutrition of Finger millet or facilitative interaction in Finger millet–horsegram intercrops (Zhang and Li, 2003; Li *et al.,* 2004). Highest Finger millet equivalent yield achieved under Finger millet–horsegram at 30 cm spacing with two weedings was due to least population of weeds and less inter-specific and intra-specific competition as compared to other intercropping systems.

Competition functions: Higher LER in intercropping treatments indicated yield advantage over monocropping due to better land utilization. Advantage from Finger millet–legume intercropping system has been reported by Banik (1996). Relative crowding coefficient, aggressivity, actual yield loss values indicated Finger millet as dominant species in a crop mixture situation. Greater competitive ability of Finger millet to exploit resources in association with horsegram has been reported by other researchers (Li *et al.,* 2002). The advantages accrued from intercropping systems, as evident from competitive functions, is due to better utilization of growth resources under cereal–legume intercropping system (Ofori and Stern, 1987). Land productivity measured by land equivalent ratio and monetary gain showed some advantages of mixed cropping of cereals and legumes (Yunusa, 1989; Mandal *et al.,* 1990).

Weed density and weed biomass: Less weed dry matter and density registered under intercropping may be due to the weed suppressing capability of intercropping over monocropping. Intercrops may demonstrate advantages on weed control over sole crops both by producing greater crop yield and less weed growth through usurping resources from weeds and also by suppressing weed growth through allelopathy (Yih, 1982). Intercrops may also provide yield advantages without suppressing weed growth below levels observed in component monocrops by using resources that are not exploited by weeds and convert resources to harvestable materials more efficiently than monocrops (Liebman and Elizabeth, 1993). Less weed production under monocropped horsegram over monocropped Finger millet may be due to better weed smothering efficiency of pulse crops (Sheaffer *et al.,* 2002; Midya *et al.,* 2005). Less weed biomass production and weed density under intercropping system is due to higher inter-specific competition combined with complementarity between intercrop species that improve the crop stand competitive ability towards weeds (Nielson *et al.,* 2003).

Nodule number and dry weight: Higher number of nodules and greater nodule dry weight under intercropping also may be due to complementarity effect; where association of cereal with legume; encourages legume component to fix more amount of nitrogen (Giller and Wilson, 1991). Effective nodules are the sites of symbiotic nitrogen fixation. Higher number of effective nodules under intercropping system over pure stand of legume is an indication that more atmospheric nitrogen fixation in the crop mixture (Maingi *et al.,* 2001). So, more nitrogen fixation may be due to more numbers of nodule formations (Thompson, 1977). Higher number of nodule may also be due to the "facilitative interaction" of intercropping (Zhang and Li, 2003; Li *et al.,* 2004).

Depth of penetration of roots and root dry matter: Higher depth of penetration of horsegram root under intercropping system may be due to the spatial complementarity where the component crops avoid the area of resources that is already depleted or being depleted by other crops. Deeper rooting component may be forced more deeper in the presence of a shallow rooting component under intercropping system (Whittington and O'Brien, 1968).

Economics: Higher net return is achieved with greater productivity. Highest returns were obtained from Finger millet–horsegram at 30 cm spacing weeded twice due to greater productivity under this treatment with comparable

cost of cultivation. Higher gross and net return under intercropping was due to higher total productivity under mixed stand with relative less input investment.

CONCLUSION

For monocrops total productivity was lower, but weed density and biomass was greater. Narrow spacing under both monocropping and intercropping reduced weed population and density. There was reduction in yield under intercropping over monocropping due to competition. However, results obtained from competition functions and economics indicated overall advantage accrued from intercropping. Since, inter-specific competition coupled with complementarity increases crop stand ability to smother weeds, intercropping systems were found to be beneficial in terms of weed management. In particular, intercropping of Finger millet and horsegram with a 30 cm row spacing weeded twice was found to be the most effective under experimental condition, for better economics, land use efficiency and for smothering weeds.

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