Indian Journal of Agricultural Sciences **82** (8): 676–80, August 2012

Effect of transpiration suppressants and nutrients on productivity and moisture-use efficiency of pearlmillet (*Pennisetum glaucum*) – pigeonpea (*Cajanus cajan*) intercropping system under rainfed conditions

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Received: 14 January 2012; Revised accepted: 7 February 2012

ABSTRACT

A field experiment was conducted at IARI, New Delhi during 2009 and 2010 to study the effect of cropping systems, transpiration suppressants and nutrient management on productivity and moisture-use-efficiency of pearlmillet (*Pennisetum glaucum* L.) – pigeonpea [*Cajanus cajan* (L.) Millsp.] intercropping system under rainfed conditions on a sandy loam soil. There was significant superiority in yield attributes as well as yield of pearlmillet and pigeonpea under sole cropping as compared to their intercropping system. Pearlmillet equivalent yield and land equivalent ratio was significantly higher with intercropping system (2:1 ratio). Intercropping system recorded the higher moisture-use-efficiency and economics as compared to either of the sole cropping. Rate of moisture use was more in sole pearlmillet (3.92 mm/day) than sole pigeonpea and intercropping system. The results showed significant improvement in all yield attributes and yield as well as moisture use and economics due to spray of transpiration suppressants over the control under inadequate moisture conditions. The total number of nodule and nitrogenase activity significantly differed in pigeonpea crop under different fertilizer doses as compared to control. Among fertility levels, application of 50 kg N + 17.2 kg P/ha, followed by 25 kg N 8.6 kg P/ha + BF resulted in better performance of crops over other treatments.

Key words: Moisture-use indices, Nutrient management, Pearlmillet, Pigeonpea, Transpiration suppressants, Yield advantage indices

Pearlmillet (*Pennisetum glaucum* L.) is a major crop in the arid and semi-arid regions. It is getting more attention today due to increasing incidence of less seasonal rainfall, terminal heat, frequent occurrence of extreme weather events coupled with scanty water resources (Singh *et al.,* 2010). Therefore, in rainfed areas intensive agriculture in the form of millets intercropping with pulses is an insurance against bad weather and which increase the land equivalent ratio, soil fertility and monetary returns considerably (Kimaro *et al.* 2009*)*. Anti-transpirant films increase the resistance to diffusion of water vapour from stomata and induce stomatal resistance. The major source of soil moisture loss is ET. Therefore, its favourable regulation is needed to tide over soil moisture loss problem. The continuous nutrient depletion is a challenge from the viewpoint of enhancing foodgrain production. The low level utilization of nutrients supplied through fertilizer calls for choosing appropriate combination of crops to utilize nutrients efficiently for long-term sustainability to get the maximum profit. However, with the changing scenario of crop improvement in millet and pulses intercropping system, there is a need to relook and investigate low cost technology. Therefore, the present experiment was conducted to study the productivity and moisture-use-efficiency of pearlmillet and pigeonpea intercropping system as influenced by transpiration suppressants and nutrient management under rainfed conditions.

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MATERIALS AND METHODS

The experiment was conducted during rainy (*kharif*) season (June–December) of 2009 and 2010 at Indian Agricultural Research Institute, New Delhi. During 2009, the rainfall was erratic with an annual precipitation of 490 mm as compared to the normal rainfall of around 650 mm. In 2010, the rainfall was above normal (850 mm). The unfavourable climate and weather conditions adversely affected the growth and development of pearlmillet and pigeonpea in 2009. Free from such adverse climatic conditions in 2010, the performance of pearlmillet and pigeonpea was better.

The soil was sandy loam in texture with *p*H 7.8, organic C 0.3%, available N 135.85 kg/ha, available P 10.4 kg/ha and available K 187.9 kg/ha. The soil moisture content at field capacity and permanent wilting point was 18.8 and 6.5%, respectively with bulk density 1.50 g/cc in 0–30 cm layer. The experiment was laid out in split plot design with 9 combinations including 3 cropping system (C_1- pearlmillet sole, C_2-pigeonpea sole, C_3-paired row of pearlmillet + one row of pigeonpea) and three transpiration suppressants [T_0-control, T_1-cycocel (200 ppm), T_2-PMA (320 ppm)] in the main plot and four fertility levels (F_0-Control, F_1- 25 kg N + 8.6 kg P/ha , F_2- 50 kg N + 17.2 kg P/ha, F_3-25 kg N + 8.6 kg P/ha + BF) in the sub plots were replicated thrice. The pearlmillet and pigeonpea was sown at 50 cm row spacing in sole cropping while paired row of pearlmillet + one row of pigeonpea (30/70 cm) in 2: 1 ratio. Pearlmillet matured in second fortnight of October, while pigeonpea in the first fortnight of December in both the years of experimentation. Fertilizer was drilled in bands 8–10 cm below the surface. Transpiration suppressants application was depended upon rainfall pattern and moisture availability to the crops. Pearlmillet seeds were inoculated with biofertilizers [*Azotobacter* and phosphate-solubilizing-bacteria (PSB)] while, pigeonpea seeds were inoculated with *Rhizobium* culture and PSB. Total volume of solution of transpiration suppressants applied was 800 litres/ha at 50 DAS.

$$\text{SCU} = \sum_{i=1}^{n} (\text{bj} + \text{ej}) + \text{effective rainfall}$$

Seasonal consumptive use (SCU) and moisture use rate are computed using the following formula:

$$\text{Moisture use rate} \left(\frac{\text{mm}}{\text{day}}\right) = \frac{\text{Consumptive use (mm)}}{\text{Crop duration (days)}}$$

RESULTS AND DISCUSSION

Yield attributes and crop yield

C_1 showed higher yield attributes and yield over C_3 (Tables 1, 2). The magnitude of increased being 11.3, 8.4, 44.6 and 6.7% productive earhead, length of earhead, girth of earhead, grain weight/earhead, respectively in sole cropping over the intercropping system. The grain yield of intercropped pearlmillet decreased by 6.9 and 9.9% in intercropping system as compared to sole stand of pearlmillet in 2009 and 2010, respectively (Table 2). This might be due to changing of planting pattern with adjustment of one row of pigeonpea after two rows of pearlmillet (2:1 ratio) in intercropping system than sole stand of pearlmillet, which vary in growth attributes, yield attributes, grain and stover yield of intercropped pearlmillet than sole stand of pearlmillet. The effective branches/plant at maturity, pods/plant and grain weight/pod of pigeonpea was adversely affected in intercropping system than sole stand (Tables 1, 2). Intercropped pigeonpea, on an average, produced 17.42% less pods/plant as compared to sole stand. However, the extent of reduction in grains/pod in intercropping was of lesser magnitude when compared to its sole stand. The cumulative effect of reduction in branches/plant, pods/plant and grains/pod in intercropped pigeonpea led to its lower productivity (0.61 tonnes/ha) when compared to its sole cropping (1.52 tonnes/ha). This could be attributed to the plating pattern, which creates dissimilar conditions for plant growth and development of pearlmillet and pigeonpea in intercropping system than their sole cropping. Further, the competition effect for resources, particularly moisture and nutrients also contributes to lower values of yield attributes and yield (Kimaro *et al.* 2009).

The transpiration suppressants had significant effect on yield attributing parameters and yield of pearlmillet and pigeonpea in 2009 only (Tables 1, 2), which attributed primarily due to varying rainfall pattern and dry spell in 2009. In 2009, yield attributing parameters and yield of pearlmillet and pigeonpea were the highest at T_2, closely followed by T_1 as compared to T_0. T_1 was found less effective than T_2. Favourable effect of transpiration suppressants on the crop in 2009 attributed to the role of transpiration supplement in reducing the effect of dry spell on the crop (Tetarwal and Rana 2006).

F_2 gave significantly higher pearlmillet grain yield by 32.1, 9.4 and 5.7 and 30.7, 17.1 and 4.7% over F_0, F_1 and F_3 respectively, in 2009 and 2010. Pigeonpea receiving adequate fertilizer by different sources showed superior performance over no fertilization. The maximum grain yield of pigeonpea was also obtained with F_2 (1.17 and 1.24 tonnes/ha), followed by F_3 (1.12 and 1.16 tonnes/ha), which was 37.6 and 31.7% in 2009 and 37.7 and 28.9% higher over F_0 in 2010 (Table 2). Adequate amounts of N and P fertilization facilitate better growth and development, which ultimately increase the yield. *Azotobacter* and *Rhizobium* facilitates the atmospheric N_2 fixation while, PSB increase the P uptake due to solubilization of native phosphorous (Tetarwal and Rana 2006).

Number of nodules and nitrogenase activity of pigeonpea

Number of nodules and nitrogenase activity was significantly less under C_3 as compared to C_1 (Table 1). The total number of nodules and nitrogenase activity significantly differed in pigeonpea crop under different fertility levels where all the N levels produced lesser number of nodules as compared to control (Table 1). This might be due to the fact that legumes form an effective symbiosis with *Rhizobia* when the plants need for N is not met by the N in the soil. When there is an abundant N in the soil from mineralized organic matter or from fertilizer, there may be no nodulation and nitrogenase activity on legumes, even if they are inoculated with effective *Rhizobia* (Ghosh *et al.* 2009).

Yield advantage indices

C_3 intercropping system recorded significantly higher pearlmillet equivalent yield (PEY) as compared to either of sole cropping (Table 2). It was due to almost similar yield of intercropped pearlmillet (2.73 tonnes/ha) as that of its sole stand (2.93 tonnes/ha), and additional yield of pigeonpea (0.61 tonnes/ha) as a bonus in intercropping system. The C_3 intercropping system on an average increased PEY by 45.7 and 10.1% over sole cropping of C_1 and C_2, respectively. The higher land equivalent ratio (LER) values in C_3 indicated yield advantage over sole stand due to better land utilization. The higher LER values under C_3, i e 1.31 and 1.35 in

Table 1 Effect of cropping systems, transpiration suppressants and fertility levels on yield attributes of pearlmillet and pigeonpea as well as nitrogenase activity

Treatment	Pearlmillet								Pigeonpea									
	Productive earhead/m row length		Length of earhead (cm)		Girth of earhead (cm)		Grain weight/earhead (g)		Effective branches/m row length at maturity		No. of pods/plant		No. of grains/pod		No. of nodules (45 DAS)		Nitrogenase activity (µ mol/mg/h)	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Cropping systems																		
C_1	19.1	21.2	27.3	28.3	15.4	16.5	10.9	11.5										
C_2									15.4	16.5	148.1	149.7	3.6	3.7	20.3	18.2	2.32	2.19
C_3	17.3	18.9	25.5	25.8	10.9	11.2	10.5	10.5	10.9	11.2	125.6	128.0	3.3	3.4	18.1	16.3	2.14	2. 01
SEm±	0.5	0.7	0.4	0.6	0.31	0.25	0.11	0.28	0.31	0.25	2.18	1.83	0.08	0.08	0.54	0.26	0.05	0.06
CD (*P*=0.05)	1.6	2.2	1.3	1.9	0.99	0.78	0.35	0.89	0.99	0.78	6.86	5.76	0.25	0.26	1.69	0.83	0.16	0.17
Transpiration suppressants																		
T_0	16.7	19.4	25.1	26.7	12.2	13.4	10.3	10.8	12.2	13.4	130.4	136.1	3.2	3.5				
T^1	18.8	20.1	26.9	27.1	13.6	13.9	10.8	11.1	13.6	13.9	189.4	139.8	3.6	3.6				
T^2	19.0	20.6	27.0	27.4	13.8	14.2	11.0	11.2	13.8	14.2	189.7	140.2	3.6	3.7				
SEm±	0.64	0.90	0.52	0.77	0.38	0.31	0.14	0.34	0.38	0.31	2.67	2.24	0.10	0.10				
CD (*P*=0.05)	2.02	NS	1.64	NS	1.21	NS	0.43	NS	1.21	NS	8.41	NS	0.31	NS				
Fertility levels																		
F_0	15.4	17.1	24.6	24.6	10.7	11.2	9.32	9.6	10.7	11.2	126.1	127.0	3.0	3.6	21.2	18.6	2.48	2.27
F_1	17.6	19.3	26.2	26.7	13.4	13.7	10.5	10.7	13.4	13.7	135.6	137.0	3.4	3.5	19.5	17.3	2.24	2.08
F_2	20.6	22.4	27.9	28.9	14.7	15.6	11.8	12.1	14.7	15.6	145.0	147.4	3.8	3.9	16.1	15.6	1.91	1.86
F_3	19.2	21.3	26.8	28.1	13.9	14.7	11.3	11.7	13.9	14.7	140.7	142.1	3.6	3.8	20.1	17.5	2.29	2.16
SEm±	0.60	0.74	0.41	0.67	0.37	0.38	0.29	0.39	0.37	0.38	2.09	2.13	0.10	0.12	0.48	0.36	0.04	0.05
CD (*P*=0.05)	1.73	2.12	1.17	1.93	1.06	1.10	0.83	1.10	1.06	1.10	6.00	6.10	0.29	0.34	1.39	1.04	0.13	0.15

Table 2 Effect of cropping systems, transpiration suppressants and fertility levels on yield and yield advantage indices

Treatment	Pearlmillet yield (tonnes/ha)		Pigeonpea yield (tonnes/ha)		Pearlmillet equivalent yield (tonnes/ha)		Land equivalent ratio (LER)	
	2009	2010	2009	2010	2009	2010	2009	2010
Cropping systems								
C_1	2.93	3.34			2.93	3.34	1.00	1.00
C_2			1.50	1.54	4.09	4.20	1.00	1.00
C_3	2.74	3.04	0.57	0.65	4.31	4.82	1.31	1.35
SEm±	0.05	0.04	0.01	0.02	0.04	0.17	0.04	0.10
CD (*P*=0.05)	0.15	0.11	0.03	0.06	0.16	0.54	0.12	0.32
Transpiration suppressants								
T_0	2.69	3.14	1.01	1.07	3.62	3.99	1.09	1.10
T^1	2.89	3.19	1.04	1.09	3.81	4.15	1.10	1.11
T^2	2.93	3.24	1.05	1.12	3.89	4.19	1.12	1.14
SEm±	0.06	0.04	0.01	0.02	0.04	0.17	0.04	0.10
CD (*P*=0.05)	0.19	NS	0.03	NS	0.16	NS	NS	NS
Fertility levels								
F_0	2.37	2.73	0.85	0.90	3.16	3.39	1.07	1.10
F_1	2.86	3.05	1.00	1.08	3.63	3.96	1.11	1.11
F_2	3.13	3.57	1.17	1.24	4.22	4.68	1.12	1.15
F_3	2.96	3.41	1.12	1.16	4.10	4.41	1.12	1.12
SEm±	0.06	0.03	0.01	0.04	0.04	0.09	0.07	0.02
CD (*P*=0.05)	0.17	0.09	0.04	0.10	0.15	0.28	NS	NS

respective years clearly indicate 31% and 35% advantage over sole stand (Table 3). The results are in accordance with the Kimaro *et al.* (2009).

The total productivity in terms of PEY was markedly affected by transpiration suppressants in 2009 only (Table 2). T_2, being at par with T_1, recorded significantly higher PEY over T_0. It might be due to increased grain yield of pearlmillet and pigeonpea by extendable period of moisture availability. Transpiration suppressants also slightly increased the LER values than control. The highest LER values were obtained with T_2, i e 1.12 and 1.14 over T_0 (1.09 and 1.10) in 2009 and 2010, respectively (Table 3). The findings are in conformity with those of Ghosh *et al*. (2009).

The maximum LER values were obtained with F2, followed by F3 as compared to other fertilizer doses (Table 3). The per cent increase in PEY was 7.8, 6.9, 9.0 and 7.8, 8.7, 8.8% with the application of F2 over F0, F1 and F3 in 2009 and 2010, respectively. The findings are in conformity with those of Ghosh *et al.* (2009).

Moisture-use indices

C_3 intercropping system on an average register 76.4 and 102.8 mm more consumptive use and thus has 1.62 and 5.92 kg/ha-mm more moisture-use-efficiency (MUE) than C_1 and C_2, respectively (Table 3). The higher consumptive use and MUE due to the grain yield of both the crops were proportionately higher under intercropping than the amount of water used for biomass production. Pearlmillet intercropped with pigeonpea utilized more water for evapotranspiration and metabolic activities. Moisture use rate was more in C_1 (3.92 mm/day) than C_2 (2.31 mm/day) and C_3 (3.00 mm/day). It could be attributed to the shorter duration of pearlmillet as compared to longer duration of pigeonpea and intercropping with the same moisture level. C_3 Intercropping system increased consumptive use of water by 21.4 and 31.62% over sole cropping of pearlmillet and pigeonpea, respectively. Similar results were reported by Tetarwal and Rana (2006).

The maximum MUE was recorded with T_2 (8.23 kg/ha-mm), followed by T_1 (8.1 kg/ha-mm) spray and the minimum with T_0 (7.94 kg/ha-mm). This might be due to the availability of more moisture under transpiration suppressants spray for a longer period of time for proper growth and development of crops. Moisture use rate was also higher with transpiration suppressants spray because of more absorption and utilization of water for metabolic activities. Similar results have also been reported by (Tetarwal and Rana 2006).

The highest MUE was recorded with F_2 (3.27 kg/ha-mm), followed by F3 (3.15 kg/ha/mm) and lowest with F0 (2.83 kg/ha-mm) (Table 3). It enhanced the consumptive use and MUE by 14.10, 5.18 and 1.77 and 16.84, 9.97 and 0.70% over F_0, F_1 and F_2, respectively. It might be due to increase in yield of higher magnitude than the corresponding increase in consumptive use of water, eventually resulting in considerable increase in moisture-use efficiency due to increased fertility levels (Singh *et al.,* 2010). Moisture use were also increased with different fertility levels that might

Table 3 Effect of cropping systems, transpiration suppressants and fertility levels on moisture use indices and economics (mean of two years)

Treatments	Moisture use indices			Economics		
	Consumptive use (mm)	MUE (kg/ha-mm)	Moisture use rate (mm/day)	Cost of cultivation (x10³'/ha)	Net returns (x10³'/ha)	B: C value
Cropping systems						
C_1	367.17	8.95	3.92	11.12	25.03	2.25
C_2	340.77	4.65	2.31	11.42	25.28	2.21
C_3	443.59	10.57	3.00	12.74	38.13	2.99
SEm±	3.82	0.15	0.04			
CD (*P*=0.05)	11.41	0.44	0.12			
Transpiration suppressants						
T_0	364.78	7.94	2.93	11.30	28.36	2.50
T^1	391.54	8.10	3.11	11.97	29.76	2.48
T^2	394.71	8.23	3.18	12.00	30.32	2.52
SEm±	3.82	0.15	0.04			
CD (*P*=0.05)	11.41	NS	0.12			
Fertility levels						
F_0	352.40	7.36	2.83	11.13	22.94	2.05
F_1	382.40	7.82	3.04	11.78	28.16	2.39
F_2	402.22	8.60	3.27	12.24	34.26	2.80
F_3	395.22	8.54	3.15	11.88	32.57	2.74
SEm±	2.13	0.08	0.02			
CD (*P*=0.05)	6.05	0.24	0.06			

have attributed to enhanced vegetative growth and extensive root system that enabled the plants to utilize more moisture from soil layers (Tetarwal and Rana 2006).

Economics

C_3 intercropping system on an average fetched ₹ 13.1×10^3 and 12.58×10^3/ha more net returns and thus has 0.74 and 0.78 more B: C ratio than C_1 and C_2, respectively (Table 4). The higher PEY coupled with the corresponding stover yield and with minimal increases in cost of cultivation has resulted in higher net returns and B:C ratio in pearlmillet and pigeonpea system. C_3 increased mean net returns and B: C ratio by 52.33 and 50.83% and 32.88 and 35.29% over sole cropping of pearlmillet and pigeonpea, respectively. Similar results were reported by (Tetarwal and Rana, 2006).

Transpiration suppressants showed considerable variation in net returns as well as B: C ratio. T_2 fetched the highest net returns ₹ 24.42×10^3 over T_0 (₹ 22.11×10^3) (Table 4). B: C ratio under T_2 was recorded higher B:C ratio than T_1. Transpiration suppressants were less economical in 2010. Similar results were reported by Tetarwal and Rana (2006).

F_2 enhanced mean net returns by ₹ 11.32×10^3/ha over F_0. Further, F_3 enhanced net returns by ₹ 9.63×10^3/ha over F_0 (Table 3). Inclusion of biofertilizers with F_3 enhanced the net returns by ₹ 4.41×10^3/ha over only F_1. The highest B: C ratio was observed with F_2 (2.80), followed by F_3 (2.74). The higher net returns with combined fertilizer source were due to higher PEY. F_2 increased the mean net returns and B: C ratio by 49.3 and 36.5, 21.6 and 17.1 and 5.2 and 2.2% over F_0, F_1 and F_3, respectively. Similar findings were reported by Ghosh *et al.* (2009).

Thus results of the present investigation clearly demonstrate that pearlmillet + pigeonpea intercropping system in 2:1 (70/30 cm) row ratio can be practised to achieve better land utilization, high yield as well as profitability and moisture-use-efficiency than their sole crop at 50 cm row spacing under rainfed sandy loam soils. Use of transpiration suppressants (PMA and cycocel) was found useful in year of low rainfall and dry spells. Application of 50 kg N + 17.2 kg P/ha (F2) was found to be more productive over other fertilizer doses.

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