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ORIGINAL RESEARCH ARTICLE

PRODUCTIVITY AND ECONOMICS OF MOTH BEAN (*VIGNA ACONITIFOLIA* JACQ. MARECHAL) AND PEARL MILLET (*PENNISETUM GLAUCUM* L. R. BR.) INTERCROPPING SYSTEMS UNDER LATE SOWING IN EXTREME ARID RAINFED CONDITIONS

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Abstract: A field experiment was conducted during *Kharif* seasons of 2007 to 2009 at Jaisalmer to evaluate moth bean (*Vigna aconitifolia* Jacq. Marechal) var. CZM-1 and pearl millet (*Pennisetum glaucum* L. R. Br.) var. Raj 171 intercropping systems under late sowing in extreme arid rainfed conditions of Thar desert. Five intercropping combinations of moth bean and pearl millet (2:1, 1:2, 3:1, 1:3 and 2:2) along with sole moth bean and pearl millet treatment were sown in first fortnight of August with the onset of monsoon. Sole moth bean was found superior than other treatments. The highest (0.36 Mg/ha) moth bean equivalent yield (MEY), gross return (US$ 190.1/ha), net return (US$ 98.1/ha) and B: C ratio (2.03) were obtained in sole moth bean. The lowest MEY (0.149 Mg/ha), gross return (US$ 114.9/ha), net return (US$ 46.3/ha) and B: C ratio (1.67) were obtained in sole pearl millet. Intercrop treatments have intermediate values. Low values of various competition functions viz. relative crowding coefficient, competitive ratio, aggressivity, and land equivalent ratio in various intercropping treatments further confirmed the unsuitability of intercropping treatments. Thus, sole moth bean was found suitable under late sown rainfed conditions of Indian Thar.

Keywords: Delayed sowing; Extreme arid; Gross return; Intercropping; Monsoon conditions; Moth bean; Pearl millet

INTRODUCTION

The extreme arid Thar desert is characterized by extremes of temperature, low and erratic rainfall, high wind speed and thus, very high evapotranspiration. The combined effect of climatic factors results in frequent crop failure and agricultural economy in the region [1]. The farmers of the region thus believe in low input-low risk-low yield concept [2]. Rainfed farmers traditionally grow a mixture of crops viz. pearl millet (*Pennisetum glaucum* L. R. Br.), guar seed (*Cyamopsis tetragonoloba* L. Taub.), moth bean (*Vigna aconitifolia* Jacq. Marechal), seasamum (*Sesamum indicum* L.), sonamukhi (*Cassia angustifolia*) etc. depending upon the onset of monsoon. Mixed cropping provides an insurance against failure of some crops due to vagaries of nature, particularly drought but plants do not get the opportunity to properly utilize available resources like land, nutrients, moisture etc. Moreover, mixed cropping creates the hindrance in many cultural operations like weeding, hoeing, pest control and harvesting. Thus, intercropping, which involves component crops of different growth pattern for extended use of resources, is viable options for arid conditions. Under extreme arid conditions, generally arid legumes (moth bean and guar seed) are selected as one of the components crops with pearl millet in mixed cropping. The pearl millet and guar seed grown in alternate rows (1:1) gave mean combined dry matter yield at par with sole cropping of pearl millet, but recorded significantly higher yield over mixed cropping systems [3]. Total productivity of intercropping system of cow pea and moth bean in sunflower was 74 % higher over pure cropping of sunflower [4]. Similarly, highest yield advantage of pearl millet was obtained with moth bean (1:1) and cluster bean (2:2) intercropping [5].

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During recent decades frequent delay in onset of monsoon was experienced at Jaisalmer. Sowing of pearl millet is not economic under late sown situation and moth bean is a viable option under such situation. However, farmers still mixed/ intercrop pearl millet with moth bean to fulfill fodder/grain requirement of the household. But the information on the over all productivity of moth bean and pearl millet intercropping systems under delayed monsoon situation is not available. Hence present investigation was aimed to study the compatibility of pearl millet as an intercrop with moth bean under late rainfed sowing in extreme arid conditions of Jaisalmer.

MATERIALS AND METHODS

The geographical setting

The experiment was conducted in consecutive three *Kharif* seasons of 2007 to 2009 at the experimental Chandan Farm (26°59'42"N Latitude, 71°20'08"E Longitude) of Central Arid Zone Research Institute, Regional Research Station, Jaisalmer. It is situated at the heart of Thar Desert in western most part of the country.

The climate

The agro-climatic situation of Jaisalmer district is characterized by low and erratic rainfall, high wind speed, extreme of temperatures, high evapotranspiration rate, severe wind erosion and thus, frequent droughts and famines. The overall climate is categorized under *Marusthali,* hot, hyper arid eco-sub region [6]. Long term normal rainfall in the area is 164.0 mm. Generally the monsoon sets in during the second week of July and starts receding by the end of August or in the first week of September [7].

Just 4 rain events were recorded during crop season 2007 (30 July- 56.4 mm, 31 July- 8.4 mm, 9 September- 32.2 mm and 13 September- 22.0 mm). There was an intermittent dry spell of almost 40 days (1 August to 9 September) immediately after the first shower (Fig. 1). In total 119.1 mm rainfall was received during crop season and the season was categories as below normal monsoon. During 2008, first rain spell was on 7 August and above normal monsoon rainfall of 221.0 mm was received in 11 rainy days at regular intervals up to 23 August. Thereafter, there was almost a complete dry spell for the remaining crop season. During 2009, monsoon reached Jaisalmer in first week of August and almost 76% precipitation was received in just two rain events (25 mm and 82 mm, respectively) in 14 days interval. Last rain was received on September 2. In total 140.0 mm rainfall was received during the season and was found in normal range of monsoon.

The mean daily temperature was above 30°C during August and September in all the three years (30.7 to 32.3°C). Thereafter it gradually declined around 24°C at mid November. Over three study years average wind speed was 12.4, 7.2 and 5.1 km/hr during August, September and October months, respectively. The potential evapotranspiration ranged between 4.8 to 7.7, 4.9 to 5.2 and 4.3 to 6.9 mm/day during crop season of 2007, 2008 and 2009, respectively.

The soils

The experiment was laid out in almost level (0-1% slope) aeolian plain. The soils of the sites were classified as deep, mixed, hyperthermic, calcareous family of Typic Torripsamments (Table 1). The soils were low in organic carbon (0.12 %) and available N content (207 kg $KMnO_4$-N/ha), medium in P (14 kg P/ha) and K content (138 kg K/ha). These almost level, well drained, very deep sandy loam soils with 4.0 to 6.2 % free $CaCO_3$ content provide sufficient soil volume and condition for *in situ* rain water conservation and penetration of crop roots deeper into sub surface soils. However, alkaline condition of the soils (pH> 8.0) imposed slight limitation for successful rainfed cultivation.

Table 1: Physio-chemical properties of the soils of the experimental site

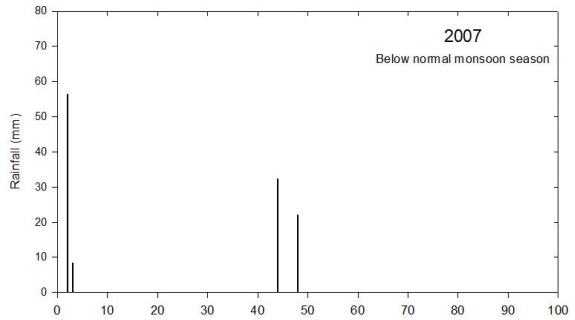
Horizon	Depth (cm)	Particle size distribution			$CaCO_3$ (%)	pHe	ECe dSm^{-1}	Organic carbon (%)	CEC (Cmol (+p)/kg)
		Sand (%)	Clay (%)	Texture					
Mixed, hyperthermic, calcareous family of Typic Torripsamments									
Ap	0-20	77.4	6.1	ls	5.4	8.7	0.8	0.12	3.5
C1	20-55	83.2	6.8	ls	4.0	8.6	0.5	0.08	2.8
C2	55-108	86.1	6.5	ls	5.2	8.6	0.3	0.06	2.4
C2	108-137	86.7	6.7	ls	6.2	8.7	0.4	0.06	2.4

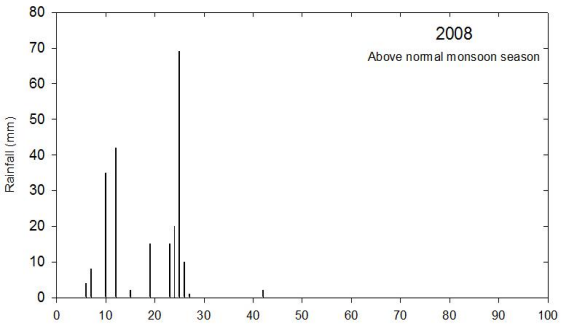
ls= loamy sand

The experimental details

An intercropping experiment on moth bean (var. CZM-1) and pearl millet (var. Raj 171) was laid out in randomized block design with three replications. The seven treatments were moth bean (sole), pearl miller (sole) and moth bean + pearl millet intercrops in the ratio of 2:1, 1:2, 3:1, 1:3 and 2:2, respectively. The crops were sown in the first week of August during 2007 and 2009 and in second week of August during 2008, immediately after the onset of monsoon. One hand weeding and thinning was carried out at 20 days after sowing (DAS). Uniform basal application of 30 kg N + 8.75 kg P/ha was applied at the time of field preparation. The crops were harvested at maturity. Moth bean equivalent yield (MEY) was worked out on the basis of existing local market price of each crop in the respective years.

For economic evaluation of the intercropping systems, prevailing market prices were used for different inputs and outputs. The prices of different produce per mega gram used for calculation were US $ 420, 525 and 360 for moth bean grains and US $ 70, 60 and 50 for moth bean straw, US $ 140, 160 and 140 for pearl millet grains and US $ 50, 40 and 40 for pearl millet straw during 2007, 2008 and 2009, respectively. The input costs used for calculation of net returns were based on the reports of the Commission for Agricultural Costs and Prices [8]. The intercropping indices, viz. relative crowding coefficient (RCC), competitive ratio (CR), aggressivity (A) and land equivalent ratio (LER) were worked out to evaluate the treatment effects reciprocity function for intercropping. Grain yield equivalent to straw yield based on prevailing local market prices was added to grain yield of both crops, since fodder is equally important in predominantly livestock based farming region. Pooled analysis of variance technique was used to compare environments (years) and means of different growth and yield attributes to draw logical conclusions [9].





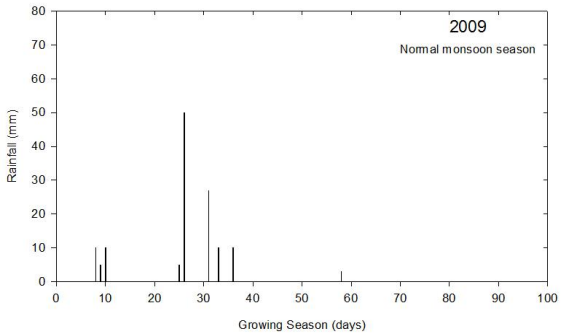


Fig.1: Distribution of rainfall in three consecutive growing seasons at extreme arid Jaisalmer in Indian Thar Desert.

RESULTS AND DISCUSSION

Crop growth

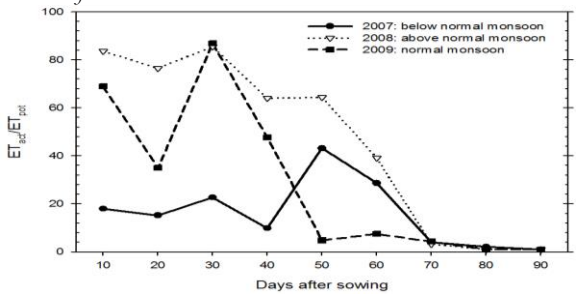
Environmental conditions during growing seasons and moth bean-pearl millet intercropping systems significantly influenced growth of both moth bean and pearl millet plants under extreme arid rainfed conditions (Table 2). Plants height of moth bean and pearl millet was significantly higher during 2008 than rest two years. Pods per plant in moth bean were significantly lower during 2007 than rest two years. Cobs per plant in pearl millet were significantly higher in 2008 than year 2007 but remained at par during 2009. Almost similar trend was found in total biomass and seed weight/plant of moth bean and pearl millet. Well distributed rainfall (221.0 mm) in 11 rainy days during 2008 supported better crop establishment, more net photosynthesis, thus larger biological frame (plant height) to further produce more photosynthates (total biomass/plant), more sinks (pods/plant, cops/plant) and eventually more seed weight/plant [10]. During 2007, first shower of 25.0 mm moderately met evapotranspiration demand for crop establishment. However, moisture stress at vegetative stage caused significant reduction in biological frame. The crops were rejuvenated marginally with second shower of 82 mm after 14 days of first rain. The intermittent moisture stress accordingly reduced overall growth and yield attributes. Contrary to this, continuous low moisture availability up to vegetative and early reproductive phases of crop significantly affected growth and yield attributes during 2007 (Fig.2). Rains at late growing season (9 and 13 September, 2007) however, slightly improved grain filling in moth bean. But losses already eventuated could not be compensated in pearl millet as clearly expressed by very low biological and seed weight/plant.

Table 2: Effect of environment (year) and intercropping treatments on growth and yield attributes of moth bean and pearl millet

Treatment	Moth bean				Pearl millet			
	Plant height (cm)	Pods/ plant	Seed weight/ plant (g)	Total biomass/ plant (g)	Plant height (cm)	Cobs/ plant	Seed weight/ plant (g)	Total biomass/ plant (g)
Environment (Year)								
2007	14.2^{b}	22.2^{b}	2.17^{b}	6.51^{b}	63.8^{b}	1.1^{b}	2.32^{b}	7.71^{b}
2008	20.9^{a}	27.4^{a}	3.17^{a}	9.14^{a}	106.9^{a}	2.0^{a}	6.92^{a}	21.11^{a}
2009	14.2^{b}	26.9^{a}	2.69^{ab}	7.24^{b}	59.9^{b}	1.5^{ab}	5.51^{a}	18.49^{a}
Intercropping System (moth bean: pearl millet)								
2:1	16.5^{bc}	27.6^{ab}	2.80^{b}	8.25^{ab}	80.9^{a}	2.0^{a}	5.46^{a}	16.45^{a}
1:2	15.9^{cd}	22.4^{c}	2.43^{c}	6.93^{c}	77.6^{ab}	1.5^{b}	4.48^{b}	14.08^{bc}
3:1	15.9^{cd}	26.5^{ab}	2.87^{ab}	8.56^{a}	75.6^{ab}	1.5^{b}	5.18^{a}	16.07^{a}
1:3	15.4^{d}	21.1^{c}	2.53^{c}	6.65^{c}	71.4^{b}	1.4^{b}	4.51^{b}	13.28^{c}
2:2	17.2^{ab}	26.0^{b}	2.50^{c}	7.67^{b}	75.3^{ab}	1.4^{b}	4.13^{bc}	15.53^{ab}
Sole moth bean	17.5^{a}	29.0^{a}	3.02^{a}	8.71^{a}	-	-	-	-
Sole pearl millet	-	-	-	-	80.3^{a}	1.3^{b}	3.74^{c}	13.21^{c}

Means within columns followed by the same letter do not differ significantly (p<0.05)

Fig. 2: Proportion of actual evapotranspiration (ETact) over potential evapotranspiration (ETpot) of moth bean during three *kharif* seasons in extreme arid rainfed conditions.



Under late rainfed sowing conditions, growth attributes shows advantage of sole moth bean crop over any intercropping combination with pearl millet. Total biomass/plant of moth bean was highest under sole cropping. Replacing moth bean rows with pearl millet up to 33% (2:1 intercropping ratio) did not decrease biomass/plant significantly. However, beyond this ratio (2:2, 1:2 and 1:3) it decreased significantly. Almost similar trend was found in plant height, pods/plant and seed weight/plant. Under rainfed condition moisture is the most limiting factor [10, 11]. The fibrous root system of pearl millet shares large rhizosphere than tap rooted moth bean and this might have significantly reduced the availability of moisture beyond a threshold level in intercropping at 2:1 and beyond. Contrary to it, sole pearl millet crop produced lowest biomass/plant. It may be due to inter and intra row competition among pearl millet plants for limited moisture. Intercropping pearl millet with moth bean successively improved the biomass plant^{-1} in proportion to its population per unit area and significantly higher biomass/plant was recorded at intercropping treatments of 2:2, 3:1 and 2:1. Intercropping pearl millet with moth bean at low proportion (3:1, 2:1 and 2:2) might have provided comparative larger rhizosphere to its prolific fibrous root system and thus, more moisture availability and

significantly higher biomass plant^{-1}. Secondly, being leguminous crop moth bean nodulation also contributes some nitrogen for pearl millet protoplasm synthesis. Similarly, the beneficial effect of arid legumes on pearl millet growth and yield was also reported [12-14].

Crop productivity

Environmental conditions and intercropping systems significantly influenced crop productivity of moth bean and pearl millet (Table 3). Significantly maximum grain yield was recorded during 2008 followed by 2009, while significantly lowest yield was recorded during 2007. The straw yield remained at par in all the three years. The straw yield remained at par in all the three years. Harvest index was significantly lower in 2007. Comparatively higher moisture availability up to late vegetative/early reproductive period during 2008 followed by 2009 insured significantly higher productivity of moth bean than 2007, when significantly lower moisture availability up to flowering stage resulted into lower grain yield (Fig. 2). However, later rains at reproductive phase encourage vegetative growth and thus, significantly reduced the harvest index while made straw yield at par with other years. Pearl millet grain yield was also significantly highest during 2008 followed by 2009 and significantly lowest grain yield was observed in 2007. Straw yield also reported similar trend. However, harvest index remained at par in all the three years. Being a determinate C_4 plant, pearl millet produced grain and straw yield according to moisture availability during the season while harvest index varied non-significantly. Grain and Straw MEY was also significantly lower in 2007 than other two years, which were at par.

Table 3: Effect of environment (year) and intercropping treatments on yield of moth bean and pearl millet

Treatment	Moth bean			Pearl millet			MEY	
	Grain yield (Mg/ ha)	Straw yield (Mg/ ha)	HI (%)	Grain yield (Mg/ha)	Straw yield (Mg/ha)	HI (%)	Grain yield (Mg/ha)	Straw yield (Mg/ha)
Environment (Year)								
2007	0.12^{c}	0.32^{a}	25.4^{b}	0.12^{c}	0.40^{c}	23.0^{a}	0.15^{b}	0.52^{b}
2008	0.25^{a}	0.48^{a}	33.4^{a}	0.37^{a}	0.96^{a}	26.9^{a}	0.31^{a}	0.96^{a}
2009	0.21^{b}	0.42^{a}	33.0^{a}	0.24^{b}	0.80^{b}	22.7^{a}	0.26^{a}	0.91^{a}
Intercropping System (moth bean: pearl millet)								
2:1	0.19^{c}	0.45^{b}	29.5^{a}	0.14^{e}	0.42^{e}	23.9^{a}	0.23^{bc}	0.76^{cd}
1:2	0.10^{e}	0.23^{d}	29.3^{a}	0.27^{c}	0.77^{c}	24.5^{a}	0.18^{c}	0.83^{bc}
3:1	0.23^{b}	0.51^{b}	30.5^{a}	0.10^{f}	0.30^{f}	23.9^{a}	0.26^{abc}	0.72^{d}
1:3	0.08^{e}	0.17^{e}	30.9^{a}	0.31^{b}	0.90^{b}	25.1^{a}	0.18^{c}	0.87^{b}
2:2	0.16^{d}	0.33^{c}	32.1^{a}	0.21^{d}	0.62^{d}	23.7^{a}	0.32^{ab}	0.82^{bc}
Sole moth bean	0.36^{a}	0.76^{a}	31.4^{a}	-	-	-	0.36^{a}	0.76^{cd}
Sole pearl millet	-	-	-	0.45^{a}	1.38^{a}	24.1^{a}	0.15^{c}	1.08^{a}

Means within columns followed by the same letter do not differ significantly (p<0.05)

Under late monsoon situations of Jaisalmer sole moth bean crop produced significantly higher grain and straw yield followed by 3:1 and 2:1 moth bean-pearl millet intercropping. The harvest index of pearl millet crop varied non-significantly among the treatments. The proportional successive reduction in yield of moth bean and pearl millet reveals lower intra-row competition among the crop at lower ratios. It may be due to more vertical than horizontal development of plant rhizosphere in search of water under extreme arid situations [2]. Overall non-significant harvest index may be due to uniform insolation, fertility and moisture availability conditions in all the intercropping treatments. However, comparative low harvest index of pearl millet may be due to low temperature at grain filling stage. At Jaisalmer, the mean temperature drastically reduce below 28°C beyond mid October. Low temperature at late reproductive stage of pearl millet caused poor grain filling and hence low harvest index [15].

Sole moth bean crop produced highest grain MEY but remained statistically at par with 3:1 and 2:2 moth bean and pearl millet intercropping. While sole pearl millet crop produced significantly highest straw MEY followed by moth bean and pearl millet intercropping ratios 1:3, 1:2 and 2:2, having straw MEY was at par with each other.

Economics

The environmental conditions significantly influenced the economic advantage (gross return, net return and B:C ratio) over the years (Table 4). Significantly highest gross return (US$ 200.4/ ha) was received in good monsoon year 2008 while significantly lowest gross return (US$ 75.5/ha) was received in poor monsoon year of 2007. Almost similar trend was recorded in net return and B:C ratio as well.

Table 4: Economics of moth bean and pearl millet intercropping systems

Treatment	Gross return (US$/ ha)	Net return (US$/ ha)	B:C ratio
Environment (Year)			
2007	75.48^{c}	32.26^{c}	1.72b
2008	200.42^{a}	102.42^{a}	2.03a
2009	135.52^{b}	59.58^{a}	1.79b
Intercropping System (moth bean: pearl millet)			
2:1	139.26^{bc}	69.74^{bc}	1.96
1:2	118.92^{de}	52.56^{d}	1.76
3:1	147.24^{b}	72.72^{b}	1.94
1:3	116.82^{e}	50.46^{d}	1.74
2:2	132.82^{bcd}	63.40^{c}	1.83
Sole moth bean	190.06^{a}	98.06^{a}	2.03
Sole pearl millet	114.90^{e}	46.34^{d}	1.67

Means within columns followed by the same letter do not differ significantly (p<0.05).

Among the intercropping treatments sole moth bean crop produced significantly maximum gross return followed by 3:1 and 2:1 moth bean-pearl millet intercropping ratios. The

lowest gross return was recorded in sole pearl millet followed by 1:3 and 1:2 intercropping ratios. Almost similar trend was recorded for net return and B: C ratios as well. Low grain yield and lower harvest index of pearl millet under delayed sowing conditions caused significantly lowest returns from pearl millet and hence influenced the comparative economics of pearl millet production either as a sole or intercrop.

Competition functions

Relative crowding coefficient (RCC) of moth bean, pearl millet and system as well was found less than unity (Table 5), and thereby confirming disadvantage of moth bean-pearl millet intercropping in extreme arid region where onset of monsoon is usually late. The results are further confirmed by low aggressivity value (A) and land equivalent ratio (LER). Aggressivity value near zero and LER values less than one suggest superiority of sole crop over intercropping. Competitive ratio (CR) of almost unity for moth bean and pearl millet in all intercropping treatments reveals minimal intra-row competition for limited water as roots of both crops become more vertically pronounced in search of water. Further, equal CR values of moth bean and pearl millet shows no advantage of intercropping over sole cropping.

Table 5: Effect of moth bean and pearl millet intercropping systems on relative crowding coefficient (RCC), aggressivity (A), competitive ratio (CR) and land equivalent ration (LER) (mean of 3 years).

Treatment	RCC			CR		A	LER
	Moth bean	*Pearl millet*	System	Moth bean	Pearl millet		
Intercropping System (moth bean: pearl millet)							
2:1	0.662	0.867	0.741	0.981	1.020	-0.063	0.856
1:2	0.781	0.705	0.720	1.023	0.978	-0.016	0.847
3:1	0.648	0.820	0.720	1.067	0.937	0.017	0.863
1:3	0.823	0.661	0.732	0.983	1.017	-0.025	0.877
2:2	0.800	0.842	0.815	0.993	1.007	-0.019	0.894

CONCLUSION

The present study shows that sole cropping of moth bean is advantageous than any moth bean and pearl millet intercropping combinations in extreme arid rainfed conditions of Indian Thar desert where onset of monsoon is usually late.

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