



Effect of crop diversification and sowing technique on productivity, economics, water productivity and soil properties of wheat (*Triticum aestivum*)-based cropping systems

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ABSTRACT

Conventionally intensive tillage and sowing practices, and existing cereal crop-based system has been declining soil fertility resulting in poor grain yield and quality. In order to enhance system-based productivity and it becomes necessary to diversify cereal crop through legume-based cropping system with conservation technology-based tillage and crop sowing method. Hence, a study was carried out during 2018–2022 under Farmer First Project (FFP) at Morena district in Madhya Pradesh (Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh) to collate the wheat (*Triticum aestivum* L.)-based four cropping systems with rainy (*khari*) season crops i.e. pearl millet [*Pennisetum glaucum* (L.) R. Br.], pigeonpea [*Cajanus cajan* (L.) Millsp.], greengram [*Vigna mungo* (L.) Hepper] and clusterbean [*Cyamopsis tetragonoloba* (L.) Taub] and two crop sowing methods, viz. conventionally tilled and permanent broad-bed furrow irrigation were used. Significantly greater improvements were recorded in grain yield of wheat-based cropping systems, net returns, wheat equivalent yield, system protein production, water productivity, net energy gains, energy productivity and soil physico-chemical properties, while saving cultivation cost, total water-use and energy input under permanent broad bed-furrow over conventional tillage and sowing method. Likewise, system-based wheat equivalent yield, system protein productivity, additional net returns, net energy gains, energy productivity and parameters of soil physico-chemical properties were significantly enhanced with pigeonpea-wheat as compared to pearl millet-wheat cropping system. The results of experiment had suggested that cropping system of wheat based can be made more productive and remunerative with the inclusion of legume crops in rainy season and sowing of crop with permanent broad-bed furrow irrigation method.

Keywords: Clusterbean, Greengram, Pearl millet, Pigeonpea, Productivity, Soil properties, Sowing, Wheat

Cereal crop based pearl millet [*Pennisetum glaucum* (L.) R.Br.]-wheat (*Triticum aestivum* L.) system is traditionally prevalent in arid and semi-arid tropics of India. The pearl millet-wheat system is depleting soil quality and resources due to cereal crop-based mono-cropping, intensive tillage and traditional crop sowing method, undulating topography and crop residue burning (Singh *et al.* 2021). For improving the biophysical and economic sustainability of this important cropping system, a shift in production system management from the conventional tillage to permanent broad-bed furrow method of sowing and diversification with legume crop in place of pearl millet grown under wheat rotation have been advocated by Singh *et al.* (2021). Raised bed method allows for a consistent crop cover to the soil, better soil water holding capacity and conservation (Singh *et al.*

2020). The direct sowing of crops on permanent broad-bed furrow, together with balanced nutrition has been reported to resulted in favourable alterations in soil moisture retention for a prolonged time (Sharma *et al.* 2011, Singh *et al.* 2021), soil physico-chemical and biological properties (Singh *et al.* 2020, Singh *et al.* 2021). Singh *et al.* (2021) also reported that direct sowing along with residue retention of previous crop and legume-based crop rotation improved soil quality parameters. In Indian conditions, border strip or flood irrigation on uneven fields results in loss of irrigation water during application, uneven distribution of soil moisture and nutrients availability leads to lower crop yield and system, poor use-efficiency of nutrients and water productivity, higher total water-use, energy utilization, declining water table and soil physico-chemical and biological properties (Singh *et al.* 2017, Singh *et al.* 2018). Present study was carried out to compare the rainy season cereal crop, pearl millet with legume crops, greengram and clusterbean based wheat cropping systems and to see the effect of sowing methods on grain and protein productivity, economics, total

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water-use, water productivity, energetics and soil physico-chemical properties.

MATERIALS AND METHODS

On-farm experiment was conducted during 2018–2022 under Farmer First Project (FFP) at Morena district in Madhya Pradesh (Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh) in Alluvial soils. The experiments were conducted at 5 locations at Santa village having an altitude of 189 mean sea level in the gird semi-arid agro-climatic zone. Long term mean annual rainfall in the area was about 650 mm, immersed mainly in monsoon months of July and August. Over the 4-years experimentation period the minimum and maximum temperature were 0 and 48°C, respectively. The total annual rainfall was 565, 628, 518 and 623 mm during 2018–19, 2019–20, 2020–21 and 2021–22, respectively. The surface (0–15 cm) soil samples were collected for analyzing soil properties before sowing of first crop and after harvest of 4th wheat. All 5 selected locations had sandy loam texture and electrical conductivity and pH of 1:2, soil water ratio was ranges from 0.36–58 dS/m and 7.76–7.98, respectively. The soils were low in content of organic carbon (3.11–3.79 g/kg), available nitrogen (181–210 kg/ha), phosphorus (10.2–11.1 kg/ha), sulphur (11.4–13.4 kg/ha), and zinc (0.39–0.50 mg/kg) and medium in potassium (195–225 kg/ha). The value for copper (0.28–0.31 mg/kg), iron (5.31–5.69 mg/kg) and manganese (3.21–4.25 mg/kg) were above from critical limits for deficiency.

The experiments were conducted with two sowing methods, conventional tillage sowing (CTS) and permanent broad bed and furrow (PBBF) irrigation with four cropping systems, pearl millet-wheat; pigeonpea-wheat; greengram-wheat; clusterbean-wheat cropping systems. Treatments were organized in factorial randomized block design (RBD) and locations are considered as replication (Panse and Sukhatme 1954) having each plot size 2500 m² (50 m × 50 m). The mean value of the treatments was compared with 5% level of critical differences for significance. The variance over 4 years were estimated by Bartlett's χ^2 test and pooled analysis to draw logical inferences of the results.

During rainy (*kharif*) season 4 crops such as pearl millet (var. hybrid), pigeonpea (var. ICPL 88039), greengram (var. SML 668) and clusterbean (var. HG 563) were seeded after 4 tillages with cultivator followed by planking with a wooden plank and sowing of crop with single box traditional seed drill in two times (one for placing of fertilizer and another for sowing) under CTS. During first year of experimentation, broad-beds were made prepared afresh after two tillages with cultivator pursued by planking and crop sowing with broad bed and furrow disc-type tines seed cum fertilizer drill, whereas in succeeding seasons they were carry on in PBBF. The width of beds (mid-furrow to mid-furrow) was 136 cm, with 100 cm wide flat top, and 22 cm depth of furrow. The row spacing of rainy season crops and winter wheat on the bed within PBBF and CTS was 30 cm and 21cm, respectively.

The pigeonpea was seeded after pre-irrigation during 3rd week of June. The pearl millet and clusterbean crop were seeded after commencement of monsoon rains during 1st week of July, while greengram in 3rd week of July in every year. After rainy season, wheat variety MP 4010 was seeded in 3rd week of November after harvest of pearl millet and greengram, whereas in 4th week of November after pigeonpea and 2nd week of December after clusterbean after pre-irrigation. The package of practices for all crops were followed as per recommendations. Harvesting of wheat after pearl millet, greengram and pigeonpea was done during 1st week of April, whereas after clusterbean, wheat crop was harvested during 2nd week of April in respective years. The border strip irrigation was applied through open channels at recommended crop growth stages in respective crops. The irrigation water volume was estimated with water meter. The methodology to calculate total water-use and water productivity was adopted by Singh *et al.* (2018). During the period of trials, the total rainwater received during the crop period in different years by different crops is given as:

Crop	Rainfall (mm)			
	2018–19	2019–20	2020–21	2021–22
Pearl millet	438	413 (1)	268 (1)	457
Pigeonpea	509 (2)	485 (2)	339 (3)	579 (1)
Greengram	395	354	240	409
Clusterbean	438 (1)	413 (1)	286 (2)	486 (1)
Wheat	17 (5)	73 (4)	18 (5)	64 (4)

Figures in parenthesis indicates number of irrigations applied.

At maturity stage the rainy season crops were manually harvested at a height of 15–20 cm for pearl millet, 10–15 cm for greengram, 20–25 cm for clusterbean, 40–50 cm for pigeonpea and 10–15 cm for wheat. The grain and straw/stalk yield was measured from net plot size. The nitrogen concentration in grain of crops was analyzed with Kjeltex-II automatic nitrogen analyzer. The concentration of protein in grains was obtained by multiplying the nitrogen concentration in grain by a factor of 6.25. To study the productivity of different cropping systems, the rainy season crop yield converted into wheat equivalent yield (Singh *et al.* 2021). The gross returns were calculated by multiplying grain yield with minimum support price, and value of straw crops was calculated with current market rates. The estimation of net return was measured with the difference between gross returns and total cultivation cost. Energy input, output and productivity were calculated with using the procedure described by Devasenapathy *et al.* (2009). The soil surface (0–15 cm depth) bulk density was measured using an in-situ core sampling method, basic infiltration rate of soil was measured after harvest of crop by double-ring infiltrometer. The organic carbon, pH (1:2 soil:water ratio), available nitrogen, phosphorus, potassium and sulphur were determined as per methods defined by Jackson (1973) and micronutrient by diethylenetriaminepentaacetic acid

(DTPA) extraction was determined by atomic absorption spectrometer.

RESULTS AND DISCUSSION

Yield of rainy season crops: The results revealed that grain and straw/stalk yield of rainy season crops (pearl millet, pigeonpea, greengram and clusterbean) grown in wheat-based cropping system significantly varied with tillage and crop sowing methods (Table 1). The grain yields of crops of rainy season significantly improved when established on PBBF as compared to CTS. The average gain in grain yield was greater with the treatment of PBBF sowing of greengram (26.3%), followed by pigeonpea (25.3%), clusterbean (19.1%) and pearl millet (18.0%) compared to CTS. Similarly, the straw/stalk yield increased significantly with PBBF compared to CTS. The crop seeded on raised beds and furrow irrigation is known to improve soil moisture in root zone and reduction in water-logging and disease pressure resulting in greater yield (Singh and Singh 2016, Singh *et al.* 2017). Removal of crop residues as well as intensive tillage practices (5 to 8 tillage operations and plunking for seed bed preparations) resulted in declined soil organic carbon and available nutrients (Singh *et al.* 2020). Likewise, productivity of crops either remained static or declining in yield with CTS (Singh *et al.* 2021).

Yield of wheat crop: The maximum grain and straw yield of wheat grown after harvest of greengram with PBBF sowing method as compared to other crops of

rainy season (Table 1). The wheat grown in sequence under clusterbean crop obtained the minimum grain and straw yield as compared to other rainy season crops due to delayed sowing of wheat reason behind late maturity of clusterbean. The sowing method of wheat with PBBF indicated improvement in grain yield by 7.8–11.5% over CTS. Likewise, significantly improvement in straw yield of 5.9–13.1% with PBBF over CTS. The enhanced yield attributing characters and yield with PBBF due to the compound effects of advance sowing, additional nutrients and improved soil physical properties (Singh *et al.* 2021), stronger water regimes and improved nutrient use-efficiency compared to CTS (Govaerts *et al.* 2009). Moreover, delayed sowing of wheat crop after optimum date is well known to decline yield of wheat (Singh *et al.* 2020). Advance sowing and appropriate placement of seed and fertilizer at proper place and increase of soil surface area of sowing under PBBF derived in greater crop stands and efficient use of nutrients resulting in maximum yield. Moreover, PBBF protects soil organic matter which helps in water retention and supply over time, slow degradation of organic matter provides longer duration availability of nutrients to plants. This increases the mineralization rate due to chemical oxidation of organic matter under CTS treatment (Singh *et al.* 2021), while time taking tillage practices resulted in delayed wheat crop showing resulted in low yield.

Economics: The cost of cultivation and net returns of system was significantly affected by tillage and crop

Table 1 Effect of crop diversification and sowing technique on yield, economics and water balance (4 years pooled data)

Treatment		Yield (t/ha)		Cultivation cost (₹/ha)	Net return (₹/ha)	Total water-use (mm/ha)	Water productivity (kg grain/ha-mm)
		Grain	Straw				
Pearl millet-	CTS	2.39 ^a	6.24 ^a	25280 ^b	37125 ^a	429 ^b	5.6 ^a
	PBBF	2.82 ^b	7.20 ^b	20448 ^a	52731 ^b	408 ^a	6.9 ^b
wheat	CTS	4.31 ^a	4.67 ^a	32136 ^b	69851 ^a	358 ^b	12.0 ^a
	PBBF	4.68 ^b	5.06 ^b	27013 ^a	82015 ^b	272 ^a	17.2 ^b
Pigeonpea-	CTS	1.74 ^a	7.38 ^a	31725 ^b	86608 ^a	555 ^b	3.1 ^a
	PBBF	2.18 ^b	8.95 ^b	25193 ^a	122462 ^b	495 ^a	4.4 ^b
wheat	CTS	4.54 ^a	5.13 ^a	32820 ^b	75402 ^a	367 ^b	12.4 ^a
	PBBF	5.02 ^b	5.46 ^b	26538 ^a	91066 ^b	289 ^a	17.3 ^b
Greengram-	CTS	0.80 ^a	1.68 ^a	23331 ^b	34574 ^a	276 ^b	2.8 ^a
	PBBF	1.01 ^b	2.01 ^b	18264 ^a	54643 ^b	259 ^a	3.9 ^b
wheat	CTS	4.78 ^a	5.26 ^a	31629 ^b	81690 ^a	341 ^b	14.0 ^a
	PBBF	5.16 ^b	5.57 ^b	24375 ^a	97374 ^b	247 ^a	20.9 ^b
Clusterbean-	CTS	1.95 ^a	3.44 ^a	27648 ^b	57600 ^a	491 ^b	3.9 ^a
	PBBF	2.30 ^b	3.91 ^b	22237 ^a	82015 ^b	418 ^a	5.5 ^b
wheat	CTS	4.16 ^a	4.51 ^a	34552 ^b	64448 ^a	381 ^b	10.9 ^a
	PBBF	4.64 ^b	5.10 ^b	27581 ^a	81977 ^b	298 ^a	15.6 ^b

CTS, Conventional tillage and sowing; PBBF, Permanent broad bed and furrow; Minimum support price for grain as per Government of India for the respective years; Average of 4 years for straw in local market @ ₹/t 2500, 2250, 2000, 1750 and 4100 for pearl millet, pigeonpea, greengram, clusterbean and wheat, respectively. Different letter within treatments indicates significant difference at 5%.

sowing methods (Table 1). The significantly lower cost of cultivation was computed under PBBF over CTS. The saving of net cultivation cost from ₹4,832–5,532/ha of crops grown during rainy season, while in wheat from ₹5,123–6,941/ha with PBBF as compared to cost of cultivation with CTS. Among system the net savings of cultivation cost from ₹9,955–12,814/ha as compared to total cost of cultivation of the systems. The lowest cost of production with PBBF was largely due to saving in cost of tillage and sowing, and irrigation water. Similarly, net returns were significantly increased with PBBF in cropping system compared with CTS. Additional net returns with PBBF sowing of rainy season crops were greater with pigeonpea (₹35,854/ha) followed by clusterbean (₹20,435/ha), greengram (₹20,069/ha) and lowest with pearl millet (₹15,606/ha), while with wheat crop varied from ₹12,164–17,129/ha grown after rainy season crops. The maximum additional net returns ₹17,529/ha with PBBF sowing of wheat crop grown after clusterbean, whereas minimum ₹12,164/ha after pearl millet over CTS. These results showed that the direct sowing technology was more beneficial under late sown conditions as compared with timely sown crop. These findings are in accord with those reported by Singh *et al.* (2021).

The system based net returns from ₹27,770–51,518/ha with PBBF sowing as compared with total net returns of cropping system with CTS. Maximum net returns were recorded with PBBF method due to saving of cost in cultivation and higher yield. Similar observations on net returns and reduction in cost of cultivation in PBBF was reported under various cropping systems as reported by Singh *et al.* (2017).

Total water-use and water productivity: All over the 4 years of study, the total water-use and water productivity for four rainy season crops and wheat was significantly lower with PBBF compared to CTS. The savings of total water-use with PBBF was maximum with winter season wheat by 21.3–27.6%, while minimum with rainy season crops (5.3–14.9%) over CTS (Table 1). Application of water for crop production was lowest in PBBF due to lower supply requirement of irrigation water in furrows and increases the infiltration opportunity time in flood irrigation system in CTS (Singh *et al.* 2021). The maximum total water-use of system of pigeonpea-wheat (850 mm/ha) followed by clusterbean-wheat (795 mm/ha), pearl millet-wheat (737 mm/ha) and least with greengram-wheat (563 mm/ha) cropping system for crop maturities was recorded (Table 2).

The water productivity under PBBF with pearl millet, pigeonpea, greengram and clusterbean were increased by 23.2, 41.9, 39.3 and 41.0%, respectively, whereas water productivity of wheat crop increased by 39.5–49.3% over CTS (Table 1). The increase in water productivity because lower irrigation water-use and higher yield due better soil moisture environment in PBBF crop sowing method (Thierfelder and Wall 2010, Singh *et al.* 2021). Similar trend of maximum water productivity under PBBF followed by CTS has also been reported by Singh *et al.* (2021). Overall, greater water productivity of wheat equivalent yield was

Table 2 Effect of crop diversification and sowing technique on average of system-based grain, protein, water balance, energetics and soil properties (4 years pooled data)

Treatment	System productivity (t/ha)	System protein productivity (t/ha)	Total water-use (mm/ha)	Water productivity (kg grain/mm)	Energy input (GJ/ha)	Net energy (GJ/ha)	Energy productivity (t/GJ)	pH*	OC* (g/kg)	BD* (Mg/m ³)	IR* (mm/h)	Available nutrients* (kg/ha)		
												N	P	K
Pearl millet - wheat	CTS	6.85	0.739	791	8.6	22.1	0.31	7.99	3.28	1.51	6.8	210	11.2	187
	PBBF	7.60	0.865	683	11.1	19.0	0.40	7.81	3.37	1.48	7.6	226	12.6	198
Pigeonpea - wheat	CTS	9.88	0.939	919	10.8	23.1	0.43	7.82	4.08	1.46	10.0	267	15.2	216
	PBBF	11.64	1.139	780	14.9	19.7	0.59	7.70	4.26	1.41	11.2	289	17.9	238
Greengram - wheat	CTS	7.66	0.746	619	12.4	19.9	0.39	7.86	3.81	1.50	7.7	234	12.7	196
	PBBF	8.77	0.867	507	17.3	17.2	0.51	7.73	3.94	1.46	8.5	247	14.3	215
Clusterbean - wheat	CTS	8.34	0.878	875	9.5	22.9	0.36	7.87	3.94	1.48	8.9	248	13.9	203
	PBBF	9.81	1.031	715	13.7	19.8	0.49	7.76	4.18	1.44	9.8	269	15.6	221
CD (P=0.05)	0.	0.37	0.06	57	0.8	0.7	0.04	0.09	0.17	0.03	0.7	16	1.2	9

*After 4th wheat harvest; OC, Organic carbon; BD, Bulk density; IR, Infiltration rate.

observed under greengram-wheat followed by pigeonpea-wheat, clusterbean-wheat, and the lowest by pearl millet-wheat cropping system.

System productivity: The PBBF crop sowing techniques had significant impact on wheat equivalent yield of system as compared to CTS (Table 2). Results revealed that PBBF sowing method enhanced wheat equivalent yield by 11.9–17.8% as compared with CTS. The wheat equivalent grain yield of cropping systems under study followed the order: pigeonpea-wheat (10.76 t/ha) > clusterbean-wheat (8.93 t/ha) > greengram-wheat (8.22 t/ha) > pearl millet-wheat (7.23 t/ha). Singh *et al.* (2021) reported that inclusion of legumes in rainy season improves soil quality which improved yield of wheat-based cropping system. Earlier, Singh *et al.* (2017) reported that root proliferation and biomass of leaf litter of pigeonpea greatly improved physico-chemical properties of soils resulting increased in yield.

System protein productivity: The crop sowing with PBBF techniques had significant effect on system protein productivity of grain over CTS (Table 2). Results showed that PBBF method increased system protein productivity by 16.2–21.3% as compared with CTS. The system protein productivity of different systems followed the order: pigeonpea-wheat (1.13 t/ha) > clusterbean-wheat (1.03 t/ha) > greengram-wheat (0.867 t/ha) > pearl millet-wheat (0.865 t/ha). The long-term conservation technology-based tillage and crop sowing methods improved soil quality (Singh *et al.* 2021) resulted in enhanced protein yield of crops and systems. Earlier, Singh *et al.* (2017) reported that root expansion and biomass of leaf litter of pigeonpea greatly improved physico-chemical properties of soils resulting maximum increased protein yield of system of pigeonpea-wheat cropping system.

Energy indices: The crop sowing with PBBF method significantly showed savings of energy inputs by 13.5–14.7% as compared to CTS (Table 2). The reduction in energy input under PBBF system is mainly because of the exclusion of tillage practices and lower irrigation water demand, which consumed a major part of energy inputs, whereas intensive tillage operations accounted for higher machinery use and fossil fuel consumption with CTS. The energy input of various crops grown in systems followed in order: pigeonpea-wheat > clusterbean-wheat > pearl millet-wheat > greengram-wheat. Similar findings were recorded in wheat crops after harvesting of pigeonpea (Singh *et al.* 2013) and clusterbean (Singh 2020). Significantly higher net energy output and energy productivity increased by 13.0–18.0% and 29.0–37.2% were obtained with PBBF over CTS, respectively. The improvement in net energy and energy productivity of system of wheat based was because of higher productivity using less energy under PBBF method.

Physico-chemical properties: The crop sown with PBBF decreased the pH and bulk density, while increased organic carbon, infiltration rate and available nitrogen, phosphorus and potassium as compared with CTS (Table 2). The PBBF crop sowing methods were increased organic carbon from 0.09–0.24 g/kg, infiltration rate (0.8–1.2 mm/h),

available nitrogen (13–22 kg/ha), phosphorus (1.4–2.7 kg/ha), potassium (11–22 kg/ha), as compared to the values of CTS, respectively. Another study showed that PBBF helps to improvement in soil organic carbon and physico-chemical characteristics owing to surface retention of more residues as compared to CTS (Singh *et al.* 2018), whereas consecutive tillage deteriorates soil organic carbon resulted in reduced fertility of soil likewise structural stability (Singh *et al.* 2021). The greater infiltration rate under PBBF may be ascribed by connected soil pores and undisturbed dead root channels. Singh *et al.* (2021) observed that tillage practices disrupt pore connectivity resulted in declining water infiltration.

In our study, it has been observed that pigeonpea-wheat as compared with other cropping systems had more positive effects on bulk density, organic carbon, infiltration rate and availability of nitrogen, phosphorus and potassium (Table 2). Deep root system and more leaf litter biomass production of pigeonpea crop (Singh *et al.* 2018) showed significant improvement in organic carbon, infiltration rate and lowering bulk density as compared with pearl millet-wheat system. Overall improvement in physico-chemical properties of soil were in the order of wheat grown in rotations with pigeonpea > clusterbean > greengram > pearl millet. Singh *et al.* (2018) observed that deep root system and its proliferation and more leaf litter biomass of pigeonpea crop improves the soil physico-chemical properties.

Among tillage and crop sowing methods, soil physico-chemical properties were significantly improved with PBBF over CTS. The wheat equivalent grain yield, protein production, economic profitability, productivity of water and energy of wheat-based cropping systems were significantly greater with PBBF over CTS. Highest wheat equivalent yield of system, protein production and economic profitability were observed in case of wheat grown after harvest of pigeonpea followed by clusterbean and greengram and lowest with pearl millet. The total water-use was recorded maximum with pigeonpea followed by clusterbean, pearl millet and least with greengram-wheat cropping system.

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