

Impact of crop diversity and sowing methods on soil characteristics, water productivity, economics, and productivity in cropping systems based on wheat (*Triticum aestivum*)

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ABSTRACT

The current cereal crop-based system and traditional heavy ploughing and sowing techniques have been reducing soil fertility, which has led to low grain production and quality. It becomes essential to diversify cereal crops using legume-based cropping systems with conservation technology-based tillage and crop sowing techniques in order to increase system-based yield. In order to collect the wheat (*Triticum aestivum* L.)-based four cropping systems with rainy (kharif) season crops, such as pearl millet [*Pennisetum glaucum* (L.) R. Br.], pigeonpea [*Cajanus cajan* (L.) Millsp.], greengram [*Vigna mungo* (L.) Hepper], and clusterbean [*Cyamopsis tetragonoloba* (L.) Taub], a study was conducted from 2018–2022 at Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh. Grain yield, net returns, wheat equivalent yield, system protein production, water productivity, net energy gains, energy productivity, and soil physico-chemical properties were all significantly improved by wheat-based cropping systems, while cultivation costs, total water use, and energy input under permanent broad bed-furrow were reduced compared to traditional tillage and sowing methods. Similarly, pigeonpea-wheat cropping considerably outperformed pearl millet-wheat cropping in terms of system-based wheat equivalent yield, system protein productivity, extra net returns, net energy gains, energy productivity, and indices of soil physico-chemical characteristics. The experiment's findings indicated that adding legume crops during the rainy season and seeding crops using a permanent broad-bed furrow irrigation technique might increase the productivity and profitability of a wheat-based cropping system.

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

Introduction

The pearl millet [*Pennisetum glaucum* (L.) R.Br.]-wheat (*Triticum aestivum* L.) cereal crop system has historically been common in India's arid and semi-arid tropical regions. Because of cereal crop-based monocropping, high tillage, traditional crop sowing methods, undulating topography, and crop waste burning, the pearl millet-wheat system is diminishing soil quality and resources (Singh et al. 2021). Singh et al. (2021) have recommended a change in production system management from conventional tillage to permanent broad-bed furrow method of sowing and diversification with legume crop in place of pearl millet grown under wheat rotation in order to improve the biophysical and economic sustainability of this significant cropping system. Consistent crop cover, improved soil water retention, and conservation are all made possible by the raised bed technique (Singh et al. 1 Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh; 2 Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh College of Agriculture. *The author's email address is ypsinghkvk@gmail.com.

2020). Direct crop planting on a permanent broad-bed furrow combined with balanced nutrition has been shown to produce favorable changes in soil physico-chemical and biological characteristics, as well as soil moisture retention for an extended period of time (Sharma et al. 2011, Singh et al. 2021). According to Singh et al. (2021), direct planting, legume-based crop rotation, and the preservation of prior crop residues all enhanced soil quality metrics. According to Singh et al. (2017) and Singh et al. (2018), border strip or flood irrigation on uneven fields in India results in the loss of irrigation water during application, uneven distribution of soil moisture and nutrient availability leads to lower crop yield and system, poor nutrient and water productivity use-efficiency, higher total water use, energy utilization, declining water table, and soil physico-chemical and biological properties. In order to compare the rainy season cereal crop, pearl millet, with legume crops, greengram, and clusterbean-based wheat cropping systems, as well as to determine the impact of planting techniques on grain and protein production, economics, and overall water usage, water productivity, soil physicochemical characteristics, and energetics.

MATERIALS AND METHODS

on the Morena district of Madhya Pradesh (Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya

Pradesh), an on-farm experiment was carried out on alluvial soils between 2018 and 2022 as part of the Farmer First Project (FFP). Five sites in the circumferential semi-arid agroclimatic zone of Santa Village, at an elevation of 189 mean sea level, were used for the tests. The region's long-term mean annual rainfall was around 650 mm, mostly during the monsoon months of July and August. The lowest and greatest temperatures for the four-year experiment were 0°C and 48°C, respectively. In 2018–19, 2019–20, 2020–21, and 2021–22, the total annual rainfall was 565, 628, 518, and 623 mm, respectively. Before the first crop was sown and after the fourth wheat crop was harvested, surface (0–15 cm) soil samples were taken in order to analyze the qualities of the soil. The sandy loam texture, electrical conductivity, and pH of each of the five sites that were chosen ranged from 0.36 to 58 dS/m and 7.76 to 7.98 dS/m, respectively. Organic carbon (3.11–3.79 g/kg), accessible nitrogen (181–210 kg/ha), phosphorus (10.2–11.1 kg/ha), sulfur (11.4–13.4 kg/ha), zinc (0.39–0.50 mg/kg), and potassium (195–225 kg/ha) were also low in the soils. The values for iron (5.31–5.69 mg/kg), manganese (3.21–4.25 mg/kg), and copper (0.28–0.31 mg/kg) above the critical levels for deficiency.

Four cropping systems were used in the experiments: pearl millet-wheat, pigeonpea-wheat, greengram-wheat, and clusterbean-wheat. Two sowing techniques were used: conventional tillage sowing (CTS) and permanent wide bed and furrow (PBBF) irrigation. Treatments were arranged using a factorial randomized block design (RBD), with each plot of 2500 m² (50 m × 50 m) and locations regarded as replication (Panse and Sukhatme 1954). The treatments' mean values were evaluated for significance at the 5% level of crucial differences. Bartlett's χ^2 test was used to quantify the variance over a 4-year period, and pooled analysis was used to make logical conclusions. Four crops, including pearl millet (var. hybrid), pigeonpea (var. ICPL 88039), greengram (var. SML 668), and clusterbean (var. HG 563), were seeded with a cultivator after four tillages during the rainy (kharif) season. The crop was then planked with a wooden planker and sown twice (once for fertilizer placement and once for sowing) under CTS. In the first year of the experiment, broad-beds were constructed again after two tillages using a tiller, followed by planking and crop sowing using a broad bed and furrow disc-type tines seed cum fertilizer drill. In the following seasons, however, they continued in PBBF. The beds were 136 cm broad from mid-furrow to mid-furrow, with a flat top that was 100 cm wide and a furrow depth of 22 cm. In PBBF and CTS, the row spacing for winter wheat and rainy season crops on the bed was 21 cm and 30 cm, respectively.

In the third week of June, the pigeonpea was sown after pre-irrigation. Every year, greengram was planted in the third week of July, while pearl millet and clusterbean crops were planted in the first week of July after the start of the monsoon rains. Following the wet season, wheat variety MP 4010 was sown in the third week of November following the harvest of greengram and pearl millet, in the fourth week of November following the harvest of pigeonpea, and in the second week of December following the pre-irrigation of clusterbean. All crops adhered to the recommended set of procedures. In the first week of April, wheat was harvested after pearl millet, greengram, and pigeonpea, while in the second week of April, wheat was harvested following clusterbean. Open channels were used to provide border strip irrigation at the appropriate crop development phases. A water meter was used to assess the amount of irrigation water. Singh et al. (2018) used this approach to determine water productivity and total water usage. The total amount of precipitation received by various crops over the trial period in various years is as follows:

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.

When the rainy season crops reached maturity, they were manually picked at heights 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 net plot size was used to calculate the grain and straw/stalk yield. The Kjeltex-II automated nitrogen analyzer was used to measure the amount of nitrogen in crop grains. The amount of nitrogen in grains was multiplied by 6.25 to get the amount of protein in grains. The rainy season crop production was converted to wheat equivalent yield in order to examine the productivity of various cropping systems (Singh et al. 2021). The value of straw crops was determined using current market prices, and the gross returns were computed by multiplying grain output by the minimum support price. The difference between gross returns and total cultivation costs was used to estimate net return. The method outlined by Devasenapathy et al. (2009) was used to determine energy intake, output, and productivity. An in-situ core sampling approach was used to determine the bulk density of the soil surface (0–15 cm depth), and a double-ring infiltrometer was used to evaluate the basic infiltration rate of the soil after crop harvest. Organic carbon, pH (1:2 soil:water ratio), accessible nitrogen, phosphate, potassium, and sulfur were measured using Jackson's (1973)

techniques, and diethylenetriaminepentaacetic acid was used as a micronutrient.

An atomic absorption spectrometer was used to assess the extraction of (DTPA).

RESULTS AND DISCUSSION

Rainy season crop yield: The findings showed that tillage and crop sowing techniques had a substantial impact on the grain and straw/stalk yield of rainy season crops (pearl millet, pigeonpea, greengram, and clusterbean) cultivated in wheat-based cropping systems (Table 1). When developed on PBBF as opposed to CTS, the rainy season crops' grain yields greatly increased. When compared to CTS, the average increase in grain production was higher with the PBBF seeding of greengram (26.3%), pigeonpea (25.3%), clusterbean (19.1%), and pearl millet (18.0%). In a same vein, PBBF considerably raised the straw/stalk yield in comparison to CTS. Raised beds and furrow irrigation are known to increase soil moisture in the root zone, reduce waterlogging and disease pressure, and increase production (Singh and Singh 2016, Singh et al. 2017). Soil organic carbon and accessible nutrients decreased as a consequence of crop residue removal and extensive tillage techniques (five to eight tillage operations and plunking for seed bed preparations) (Singh et al. 2020). Similarly, with CTS, agricultural productivity either stayed the same or decreased in yield (Singh et al. 2021). **Wheat crop yield:** The highest grain and straw yield of wheat cultivated using the PBBF planting technique during greengram harvest in comparison to other crops of season of rain (Table 1). Due to the delayed seeding of wheat, which caused the clusterbean to mature later than other rainy season crops, wheat planted in succession beneath the clusterbean crop produced the least amount of grain and straw. Wheat sown with PBBF showed a 7.8–11.5% increase in grain production compared to CTS. Similarly, there was a 5.9–13.1% increase in straw yield with PBBF compared to CTS. Stronger water regimes, greater nutrient use-efficiency in comparison to CTS (Govaerts et al. 2009), and the compound effects of advance sowing, more nutrients, and improved soil physical qualities (Singh et al. 2021) all contributed to the increased yield attributing characteristics and yield with PBBF. Furthermore, it is well known that delaying the planting of wheat beyond the ideal date can reduce wheat production (Singh et al. 2020). Increased crop stands and effective nutrient usage under PBBF are the results of advance planting, good seed and fertilizer placement, and increased soil surface area. Additionally, PBBF preserves soil organic matter, which over time aids in water retention and delivery. The gradual breakdown of organic matter gives plants access to nutrients for a longer period of time. Due to the chemical oxidation of organic matter under CTS treatment, this accelerates the pace of mineralization (Singh et al. 2021), while time-consuming tillage techniques caused a delayed wheat crop that produced a poor yield. **Economics:** Crop yields and tillage had a major impact on the system's net returns and cultivation costs.

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

Conventional tillage and sowing (CTS); permanent wide bed and furrow (PBBF); the minimum support price for grain determined by the Indian government for the relevant years; In the local market, straw takes an average of four years at ₹/t 2500, 2250, 2000, 1750, and 4100 for pearl millet, pigeonpea, greengram, clusterbean, and wheat, respectively. A substantial difference at 5% is indicated by a different letter within treatments.

(Thierfelder and Wall 2010, Singh et al. 2021). A similar trend of maximum water production under PBBF followed by CTS was shown by Singh et al. (2021). In terms of wheat equivalent yield, greengram-wheat cropping systems had the best water productivity, followed by pigeonpea-wheat, clusterbean-wheat, and pearl millet-wheat.

System productivity: When compared to CTS, the wheat equivalent yield of the system was significantly impacted by the PBBF crop planting strategies (Table 2). In comparison to CTS, the PBBF sowing technique increased wheat equivalent yield by 11.9–17.8%, according to the results. The cropping systems under investigation had the following wheat equivalent grain yields: pigeonpea-wheat (10.76 t/ha), clusterbean-wheat (8.93 t/ha), greengram-wheat (8.22 t/ha), and pearl millet-wheat (7.23 t/ha). According to Singh et al. (2021), adding legumes during the rainy season enhances soil quality, which raises wheat-based farming systems' yields. Singh et al. (2017) previously demonstrated that the biomass of pigeonpea leaf litter and root proliferation significantly enhanced the physico-chemical characteristics of soils, leading to an increase in yield.

System protein productivity: The system protein productivity of grain over CTS was significantly impacted by crop seeding using PBBF methods (Table 2). In comparison to CTS, the PBBF approach boosted system protein production by 16.2–21.3%, according to the results. Pigeonpea-wheat (1.13 t/ha), clusterbean-wheat (1.03 t/ha), greengram-wheat (0.867 t/ha), and pearl millet-wheat (0.865 t/ha) were the systems with the highest system protein production. Soil quality was improved by long-term conservation technology-based tillage and crop sowing techniques, which increased crop and system protein output (Singh et al. 2021). Prior research by Singh et al. (2017) revealed that the biomass of pigeonpea leaf litter and root extension significantly enhanced the physico-chemical characteristics of soils, leading to the highest possible protein output in the pigeonpea-wheat cropping system.

Energy indices: Compared to CTS, crop sowing using the PBBF technique considerably reduced energy inputs by 13.5–14.7% (Table 2). While intense tillage operations accounted for increased equipment usage and fossil fuel consumption with CTS, the PBBF system's decrease in energy input is mostly due to the elimination of tillage methods and reduced irrigation water demand, which consumed a significant portion of energy inputs. The order of the energy input of different crops cultivated in systems was pigeonpea-wheat > clusterbean-wheat > pearl millet-wheat > greengram-wheat. Similar results were seen in wheat harvests after the harvest of clusterbean (Singh 2020) and pigeonpea (Singh et al. 2013). PBBF significantly outperformed CTS in terms of net energy production and energy productivity, increasing by 13.0–18.0% and 29.0–37.2%, respectively. Higher production using less energy under the PBBF approach was the reason for the increase in net energy and energy productivity of the wheat-based system. **Physico-chemical characteristics:** Compared to CTS, the crop seeded with PBBF had lower pH and bulk density but higher organic carbon, infiltration rate, and accessible nitrogen, phosphorus, and potassium (Table 2). The PBBF crop planting techniques included an infiltration rate of 0.8–1.2 mm/h, an increase in organic carbon from 0.09–0.24 g/kg,

accessible potassium (11–22 kg/ha), phosphorus (1.4–2.7 kg/ha), and nitrogen (13–22 kg/ha) in comparison to CTS values. According to another study, PBBF improves soil organic carbon and physico-chemical properties because it retains more residues on the soil's surface than CTS (Singh et al. 2018). In contrast, subsequent tillage degrades soil organic carbon, which lowers soil fertility and structural stability (Singh et al. 2021). Undisturbed dead root canals and linked soil pores may be responsible for the higher infiltration rate under PBBF. According to Singh et al. (2021), tillage techniques reduce water penetration by interfering with pore connection.

According to our research, pigeonpea-wheat had more favorable impacts on bulk density, organic carbon, infiltration rate, and the availability of potassium, phosphate, and nitrogen than other cropping systems (Table 2). When compared to the pearl millet-wheat combination, the pigeonpea crop's deep root system and increased leaf litter biomass output (Singh et al. 2018) significantly improved organic carbon, infiltration rate, and bulk density. Wheat cultivated in rotations with pigeonpea, clusterbean, greengram, and pearl millet showed the greatest overall increase in the physico-chemical characteristics of the soil. According to Singh et al. (2018), the pigeonpea crop's deep root system, growth, and increased leaf litter biomass enhance the physico-chemical characteristics of the soil.

PBBF outperformed CTS in terms of soil physico-chemical characteristics among tillage and crop sowing techniques. PBBF greatly outperformed CTS in terms of wheat-based cropping systems' wheat equivalent grain yield, protein output, economic profitability, and water and energy productivity. Wheat cultivated following pigeonpea harvest had the highest wheat equivalent yield of the system, protein output, and economic profitability; clusterbean and greengram followed, and pearl millet had the lowest. The cropping system that used the most water was pigeonpea, followed by clusterbean, pearl millet,

and greengram-wheat.

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