Indian Journal of Agronomy **68** (1): 77–82 (March 2023)

Research Paper

Performance of diversified cropping sequences for productivity, profitability and land use efficiency under south-eastern Rajasthan, India

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Received: July 2022; Revised accepted: January 2023

ABSTRACT

A field experiment was conducted during 4 consecutive years (2015–16 to 2018–19) at Agricultural Research Station, Ummedganj, Kota, Rajasthan to study the performance of diversified cropping sequences for productivity, profitability and land-use efficiency under south-eastern Rajasthan. The experiment comprised 10 cropping sequences in a randomized block design with 3 replications. Maximum soybean [Glycine max (L.) Merr.] equivalent yield (8,507 kg/ha), production efficiency (31.16 kg/ha/day) and relative production efficiency (79.85%) were obtained in fodder sorghum [*Sorghum bicolor* (L.) Moench]–bitter guard [*Momordica charantia* (L.)] (low tunnel) cropping sequence. The maximum land-use efficiency of (86.51%) was observed in direct-seeded rice [*Oryza sativa* (L.)] (short duration)-desi wheat *(Triticum aestivum* L.)–summer greengram [*Vigna radiata* (L.) R. Wilczek] cropping sequence followed by short duration soybean-Indian mustard [*Brassica juncea* (L.)]–cowpea [*Vigna unguiculata* (L.)] Walp.] (vegetable + fodder) (81.85%) and sweet corn [*Zea mays* (L.)]–field pea (*Pisum sativum* var. *arvenses* (L.) Poir.)–onion [*Allium cepa* (L.)] (transplanted) (81.03%) crop sequences. Maximum and significantly higher net returns (₹163,240/ha) and relative economic efficiency (46.64%) were fetched in blackgram [*Vigna mungo* (L.) Hepper] (broad bed) + direct-seeded rice (furrow)–vegetable pea (broad bed) + coriander [*Coriandrum sativum* (L.)] (furrow)-spring greengram. The next best treatment was sweet corn–field pea–onion (transplanted), closely followed by quality protein maize (raised bed)–fennel [*Foeniculum vulgare* (L.)] (raised bed) to the tune of 39.23 and 36.69% over existing system, respectively. The maximum and significantly higher benefit: cost ratio (2.55) was fetched with quality protein maize (raised bed)–fennel (raised bed) cropping sequence, being at par with blackgram (broad bed) + direct-seeded rice (furrow)–vegetable pea (broad bed) + coriander (furrow)-spring greengram (2.52). Highest economic efficiency (₹612/ha/day) was recorded in soybean (short duration) + red gram [*Cajanus cajan* (L.) Millsp.] (2:1 row)–oat [*Avena sativa* (L.)] for fodder–summer greengram cropping sequence, followed by blackgram (broad bed) + direct seeded rice (furrow)– vegetable pea (broad bed) + coriander (furrow)–spring greengram (₹594/ha/day) and quality protein maize (raised bed)–fennel (raised bed) (₹590/ha/day). Direct-seeded rice (long duration)–berseem [*Trifolium alexandrinum* (L.)] (fodder) crop sequence had the lowest soybean-equivalent yield (4,546 kg/ha), production efficiency (16.79 kg/ha/day), relative production efficiency (–3.89%), economic efficiency (₹348/ha/day) and relative economic efficiency (–15.43%). Thus, it can be concluded that blackgram (broad bed) + direct seeded rice (furrow)-vegetable pea (broad bed)-leafy coriander (furrow)-spring greengram was found more productive and remunerative cropping sequence followed by sweet corn–field pea-onion (transplanted) and quality protein maize (raised bed) –fennel (raised bed) as diversified cropping sequences for better productivity, profitability and land use efficiency compared to existing soybean-wheat cropping system under south-eastern Rajasthan, India.

Key words: Crop diversification, Economics, Economic efficiency, Land use-efficiency, Production efficiency, System productivity

The major concern of Indian agriculture has been on increasing production of cereals, especially wheat [*Triticum astivum* (L.)] and rice [*Oryza sativa* (L.)]. Agricultural intensification increases the crop productivity but simplifies production with lower diversity of cropping systems and higher genetic uniformity. Associated detrimental effects on environment and biodiversity as well as the resilience and adaptability of cropping systems to climate change are of growing concern. The monocropping pattern also reduces resource-use efficiency. Thus, breaking the monocropping pattern by the introduction of diverse crops

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and cropping patterns helps in reviving the soil health and increasing the resource-use efficiency. Therefore, there is an urgent need to change the crops and cropping pattern that is crop diversification. It is important by way of addition of new crop(s) as intercrop and/or predecessor or successor crops, changing numbers of the crop (multi-cropping), modified cropping system and adopting a new, integrated cropping pattern with changing agronomical practices. Crop diversification may stabilize productivity of cropping systems and reduce negative environmental impacts and loss of biodiversity, but a shared understanding of crop diversification including approaches towards more systematic research is lacking.

Crop diversification refers to the addition of new crops or cropping systems to agricultural production on a particular farm. In south-eastern humid plain zone of Rajasthan, about 68.67% of farmers are comes under marginal (< 1.0-ha holding size) and small (1–2 ha holding size) farmer category (Tetarwal *et al.,* 2017). Majority of farmers of this region are following Soybean-wheat cropping sequence which is unable to fulfil the household requirements round the year. This situation needs crop-diversification options through introduction of system-based cereals, oilseeds, pulses, spices, fodder crops and other remunerative crops for their livelihood security. It was also recognized as an effective strategy for achieving the objectives of food security, nutrition security, income growth, poverty alleviation, employment generation and judicious use of land and water resources, sustainable agricultural development and environmental improvement (Hegde *et al.,* 2003). Thus, diversification of the system through introduction of crops of diverse nature may be a good preposition to break the monotony of the predominant systems and to sustain productivity. Objective of diversification was to fulfil the family need for food, nutritional security, income enhancement, employment generation, environment and soil health. Hence, performance of diversified cropping sequences for productivity, profitability and land-use efficiency was studied under south-eastern ecologies of Rajasthan.

MATERIALS AND METHODS

A field experiment was conducted at Agricultural Research Station, Agriculture University, Ummedganj, Kota, Rajasthan during 4 consecutive years (2015–16 to 2018–19). The soil of the experimental field was clay loam with slightly alkaline pH (7.56), having medium available nitrogen (394.0 kg/ha), available phosphorus (17.6 kg/ha) and high in available potassium (349.0 kg/ha) content. The experiment was laid out in randomized block design with 3 replications. The treatments comprised 10 cropping sequences, viz. T_1, soybean [*Glycine max* (L) Merr.]-(long-duration cv 'RKS 24')–wheat [*Triticum astivum* (L.)] cv 'Raj 4037'; T_2, soybean (short duration cv 'JS 95-60')–Indian mustard [*Brassica juncea* (L.) Czerny & cosson]-cv 'NRCHB 101'–cowpea [*Vigna unguiculata* (L.)] Walp.] (veg+fodder) cv 'local'; T_3, soybean (short duration cv 'JS 95-60') + red gram [*Cajanus cajan* (L.) Millsp.] cv 'Pusa-992' (2:1 row)–oat [*Avena sativa* (L.)] (fodder) cv 'JHO 822'- summer greengram [*Vigna radiata* (L.) R. Wilczek] cv 'IPM 02-03'; T_4, direct-seeded rice (short duration cv 'Pusa-1509')–wheat cv 'C-306'–summer greengram [*Vigna radiata* (L.) R. Wilczek] cv 'IPM 02-03'; T_5, direct seeded rice [*Oryza sativa* (L.)] (long duration cv 'Pusa Sugandha 5')–berseem [*Trifolium alexandrinum* (L.)] cv 'BB-2' (Fodder); T_6, transplanted rice (long duration cv 'Pusa Sugandha 5')–wheat (zero tillage) cv 'Raj 4037'; T_7, blackgram [*Vigna mungo* (L.) Hepper] (broad bed) cv 'Pratap urd 1' + direct seeded rice (furrow) cv 'PR 101'–vegetable pea (broad bed) cv 'PSM 3' + coriander [*Coriandrum sativum* (L.)] (furrow) cv 'Hisar Anand'–spring greengram cv 'IPM 02-03'; T_8, quality protein maize [*Zea mays* (L.)] (raised Bed) cv 'HQPM 5'–fennel [*Foeniculum vulgare* (L.)] (raised bed) cv 'RF 125'; T_9, sweet corn cv 'Sugar 75'–field pea [*Pisum sativaum* var. *arvensis* (L.)] cv 'IPFP 1-10'–onion [*Allium cepa* (L.)] (transplanted) cv 'N 53'; and T_{10}, fodder sorghum [*Sorghum bicolor* (L.) Moench] cv 'SSG 59-3'–bitter guard [*Momordica charantia* (L.)] (low tunnel) cv 'Sagar'. The crops were grown and managed with their recommended practices of south-eastern humid plain zone of Rajasthan. Under treatment T_7, the broad bed and furrow (BBF) was prepared manually (105 cm) and 3 rows of blackgram, vegetable pea and greengram were grown on ridge and 1 row of direct-seeded rice, leafy coriander in furrows, during respective season-wise. In T_8, ridges were made manually at a distance of 60 cm and 1 row of quality protein maize, fennel was grown seasonally. In T_{10}, low tunnels were constructed by installing 2 m wide sheets of perforated plastic over wire hoops that are spaced 1.5 m apart to moderate the temperature, suitable for advance planting of spring bitter gourd. No severe pests and diseases were observed during the crop growth; however, necessary plant-protection measures were taken on need basis. Optimum plant population was maintained for different crops.

For valid comparison between tested crop sequences, the yields (main product and by-product) of all crops were converted into soybean-equivalent yield (SEY) based on market price. Final crop yields were recorded and gross return (₹/ha) were calculated on the basis of prevailing market price of the produce. Net return was calculated by subtracting cost of cultivation from gross value of the produce, including by-product value. Benefit: cost ratio (B:C ratio) for different crop sequences was calculated as dividing net returns by cost of cultivation. Land-use efficiency (LUE) was calculated by taking total duration of crops in a sequence and divided by 365 as per Singh *et al.* (1990). Production-efficiency value was calculated by dividing total soybean-equivalent yield (kg/ha) with total duration of the crops (days) in a sequence. The relative production-efficiency (RPE) and relative economic efficiency (REE) were calculated for the comparison of diversified cropping systems with the existing soybean - wheat cropping systems and expressed in percentage (Samant, 2015):

$$RPE = (B–A)/A \times 100$$

where, A, SEY of existing cropping system; and
B, SEY of diversified cropping system.

$$REE = (B–A)/A \times 100$$

where, A, net returns of existing cropping system; and
B, net returns of diversified cropping system.

Economic efficiency value was calculated by dividing total net return (₹/ha) with total duration of the crops (days) in a sequence. The data on yield of crops and economics were recorded and subjected to statistical analysis as per Panse and Sukhatme (1985).

RESULTS AND DISCUSSION

System yield and productivity

The main product yield, by-product yield and soybean-equivalent yield of all the tested cropping sequences are given in Table 1. The total production in term of soybean-equivalent yield (SEY) was significantly higher in fodder sorghum–bitter guard (low tunnel) cropping sequence (8,507 kg/ha) over rest of the tested crop sequences, which was followed by sweet corn–field pea–onion (transplanted). The magnitude of higher system productivity (SEY) was 79.85 and 58.52% over soybean (long duration)–wheat cropping sequence, respectively. This might be owing to higher quantum in terms of yield and price of vegetable crop. The next best treatment was blackgram (broad bed) + direct-seed rice (furrow)–vegetable pea (broad bed) + coriander (furrow)–spring greengram cropping sequence by recording 42.26% higher SEY over existing soybean (long duration)–wheat cropping sequence and being at par with quality protein maize (raised bed)–fennel (raised bed), soybean (short duration) + red gram (2:1 row)–oat (fodder)–summer greengram and direct-seeded rice (short duration)–wheat (desi)–summer greengram crop

Table 1. Effect of diversified cropping sequences on main product yield, by-product yield and soybean-equivalent yield under south-eastern humid ecologies of Rajasthan (pooled mean 2015–16 to 2018–19)

Cropping sequence	Yield (kg/ha)						Soybean-equivalent yield (kg/ha)
	Rainy season		Winter season		Summer season		
	Main product	By-product	Main product	By-product	Main product	By-product	
Soybean (long duration)–wheat	1,162	1,798	5,599	7,640	–	–	4,730
Soybean (short duration)–Indian mustard–cowpea (veg + fodder)	1245	1,804	2,249	3,479	3928	16,690	5,606
Soybean (short duration) + red gram (2 : 1 row)–oat (fodder)–summer greengram	540 (1,771)	634 (2,959)	49,488	–	700	1,038	6,451
Direct seeded rice (short duration)–wheat (desi)–summer greengram	3,860	5,027	4,109	6,378	493	650	6,428
Direct seeded rice (long duration)–berseem (fodder)	4,120	5,394	83,466	–	–	–	4,546
Transplanted rice (long duration)–wheat (zero tillage)	4,417	5,930	5,003	6,487	-	-	5,953
Blackgram (broad bed) + DSR (furrow)–veg pea (broad bed) + coriander (furrow)–spring greengram	1,121 (205)	1,521 (317)	6,054 (3,498)	1,616	860	1,274	6,729
Quality protein maize (raised bed)–fennel (raised bed)	3,424	5,560	2,020	3,250	-	-	6,465
Sweet corn–field pea–onion (transplanted)	11,504	33,434	1,348	1,757	4,913	-	7,498
Sorghum (fodder)–bitter gourd (low tunnel)	52,051	–	12,167	–	–	–	8,507
SEm±	–		–	–	–	–	118
CD (P=0.05)	–	–	–	–	–	–	333

*Figures in parentheses are intercrop yields; DSR; direct-seeded rice sequences. The lowest system productivity (4,546 kg/ha) was recorded in direct seeded rice (long duration)–berseem (fodder) cropping sequence (Table 1). These results are in accordance with the findings of Samant (2015), who recorded significantly higher rice-equivalent yield in rice–brinjal, followed by rice–tomato and rice–onion owing to higher yield and price of vegetable crops. Saroch *et al.,* (2005) also reported higher system productivity by replacing wheat with vegetables in rice–wheat cropping system owing to its higher yield and market price. Inclusion of pulses in crop sequence also increased the grain yield of component crops in the sequences. This can be attributed to the legume effect of blackgram and greengram on succeeding rice crop (Yadav *et al*., 2005). The systems containing vegetable (okra), rice yield was significantly higher owing to residual effect of high doses of fertilizers and organic manures applied to vegetables that might have caused benefits to rice. Samui *et al.,* (2001) and Ray *et al.,* (2009) reported similar result with potato and okra.

Crop duration and land-use efficiency

The maximum crop duration (316 days) was taken in direct-seeded rice (short duration)– wheat (desi)–summer greengram crop sequence, followed by 299 days in soybean (short duration)–Indian mustard–cowpea (veg + fodder) and 296 days in sweet corn–field pea–onion (transplanted) while, the lowest was in soybean (long duration)–wheat cropping sequence (239 days) (Table 2). Thus, maximum land-use efficiency (LUE) (86.51%) was observed in direct-seeded rice (short duration)–wheat (desi)–summer greengram cropping sequence, followed by soybean (short duration)–Indian mustard–cowpea (veg + fodder) (81.85%) and sweet corn–field pea–onion (transplanted) (81.03%) crop sequences owing to more cropping intensity and utilized land for longer durations. Samant (2015) observed that in rice-based crop sequences, the maximum land-use efficiency was recorded in rice–brinjal sequence. Multiple cropping, using short-duration crop cultivars and better management, is a common way of increasing LUE. In the experiments carried out in different parts of country, multiple cropping systems with high land-use efficiency identified were: pigeonpea–wheat for Chambal command (Tomar and Tiwari, 1990) and rice–potato–greengram for western Uttar Pradesh (Govinda Krishnana *et al.,* 1990).

Production and relative production efficiency

The production efficiency and relative production efficiency are given in Table 2. The maximum production efficiency (31.16 kg/ha/day) and relative production efficiency (79.85 %) were obtained in sorghum (fodder)–bitter guard (low tunnel) cropping sequence. The next best treatment in respect to production efficiency was soybean (short duration + red gram (2:1)– Oat (fodder) summer greengram and in respect of relative production efficiency,

Table 2. Effect of diversified cropping sequences on land-use efficiency, production efficiency and relative production efficiency under south-eastern humid ecologies of Rajasthan (pooled mean 2015–16 to 2018–19)

Cropping sequence	Crop duration (days)				Land-use efficiency (%)	Production efficiency (kg/ha/day)	Relative production efficiency (%)
	Rainy season	Winter season	Summer season	Total			
Soybean (long duration)–wheat	100	139	0	239	65.34	19.83	0.00
Soybean (short duration)–Indian mustard–cowpea (veg + fodder)	87	130	82	299	81.85	18.76	18.52
Soybean (short duration) + red gram (2 : 1 row)–oat (fodder)–summer greengram	87	87	67	241	65.96	26.80	36.38
Direct-seeded rice (short duration)–wheat (desi)– summer greengram	106	143	67	316	86.51	20.36	35.90
Direct-seeded rice (long duration)–berseem (fodder)	118	153	0	271	74.18	16.79	–3.89
Transplanted rice (long duration)–wheat (zero tillage)	111	137	0	248	68.01	23.98	25.86
Blackgram (broad bed) + DSR (furrow)–veg pea (broad bed) + coriander (furrow) –spring greengram	85	118	72	275	75.27	24.49	42.26
Quality protein maize (raised bed)–fennel (raised bed)	90	168	0	258	70.62	25.08	36.68
Sweet corn–field pea–onion (transplanted)	86	127	83	296	81.03	25.35	58.52
Sorghum (fodder)–bitter gourd (low tunnel)	109	164	0	273	74.79	31.16	79.85

DSR, direct-seeded rice

it was sweet corn–field pea–onion (transplanted). Thus, all the diversified cropping sequences exhibited higher production efficiency than existing soybean (long duration)–wheat cropping sequence (19.83 kg/ha/day) except soybean (short duration)–mustard–cowpea (vegetable + fodder) and direct-seeded rice (long duration)– berseem (fodder) system, which observed lower PE (18.76, 16.79 kg/ha/day, respectively). This might because of more production/unit area/unit time. Our results confirm the findings of Mukesh *et al.,* (2014) and Samant (2015).

Cost of production and economics

Results revealed that, all the tested diversified cropping sequences revealed higher cost of production than the existing soybean (long duration)–wheat cropping sequence and maximum cost (₹131,757/ha) was incurred in sorghum (fodder)–bitter guard (low tunnel) followed by sweet corn–field pea–onion (transplanted) cropping sequence (Table 3). All the diversified cropping sequences fetched significantly higher net returns over existing soybean (long duration)–wheat cropping sequence except direct-seeded rice (long duration)–berseem (fodder) crop sequence (Table 3). The maximum and significantly higher net returns (₹163,240/ha) were fetched in blackgram (broad bed) + DSR (furrow)–veg pea (broad bed) + coriander (furrow)–spring greengram over rest of the crop sequences. It was higher to the magnitude of 46.64% over existing soybean–wheat sequence. The next best treatment was sweet corn–field pea–onion (transplanted), followed by quality protein maize (raised bed)–fennel (raised bed) cropping sequence to the tune of 39.23 and 36.69% over the existing system, respectively, and found at par with each other. The maximum and significantly higher benefit: cost (2.55) was fetched with quality protein maize (raised bed)–fennel (raised bed) cropping sequence being at par with blackgram (broad bed) + DSR (furrow)–veg pea (broad bed) + coriander (furrow)–spring greengram (2.52) over rest of the crop sequences with the magnitude of 7.14 and 5.88% higher over existing soybean (long duration)–wheat cropping sequence. The lowest benefit: cost ratio (1.15) was recorded in sorghum (fodder)–bitter guard (low tunnel), followed by sweet corn–field pea–onion (transplanted) (1.67) due to higher cost of production of vegetable components in these cropping sequences (Table 3).

Economic efficiency and relative economic efficiency

The highest economic efficiency (₹612/ha/day) was recorded in soybean (short duration) + redgram (2:1 row)–oat (fodder)–summer greengram cropping sequence, followed by blackgram (broad bed) + DSR (furrow)–veg pea (broad bed) + coriander (furrow)–spring greengram (₹594/ha/day) and quality protein maize (raised bed)–fennel

Table 3. Effect of diversified cropping sequences on economics, economic efficiency and relative economic efficiency under south-eastern humid ecologies of Rajasthan (pooled mean 2015–16 to 2018–19)

Cropping sequence	Cost of cultivation (×10³ ₹/ha)	Net returns (×10³ ₹/ha)	Benefit: cost ratio	Economic efficiency (₹/ha/day)	Relative economic efficiency (%)
Soybean (long duration)–wheat	47.13	111.32	2.38	467	0.00
Soybean (short duration)–Indian mustard–cowpea (veg + fodder)	57.30	129.72	2.27	434	16.53
Soybean (short duration) + red gram (2:1row)–oat (fodder)– summer greengram	70.42	147.28	2.10	612	32.31
Direct-seeded rice (short duration)–wheat (desi)–summer greengram	76.57	136.51	1.79	432	22.63
Direct-seeded rice (long duration)–berseem (fodder)	56.37	94.14	1.68	348	-15.43
Transplanted rice (long duration)–wheat (zero tillage)	62.94	134.13	2.15	540	20.49
Blackgram (broad bed) + DSR (furrow)–veg pea (broad bed) + coriander (furrow) –spring greengram	64.99	163.24	2.52	594	46.64
Quality protein maize (raised bed)–fennel (raised bed)	59.80	152.16	2.55	590	36.69
Sweet corn–field pea–onion (transplanted)	93.10	154.99	1.67	524	39.23
Sorghum (fodder)–bitter gourd (low tunnel)	131.76	150.63	1.15	552	35.31
SEm±	–	3.60	0.05	–	–
CD (P=0.05)	–	10.16	0.14	–	–

DSR, direct-seeded rice

(raised bed) (₹590/ha/day). All the diversified cropping sequences showed higher relative economic efficiency (REE) over the existing soybean–wheat system. The direct-seeded rice (long duration)–berseem (fodder) crop sequence revealed, negative REE (Table 3). The maximum relative economic efficiency (46.64%) was observed with blackgram (broad bed) + DSR (furrow)–veg pea (broad bed) + coriander (furrow)–spring greengram, followed by sweet corn–field pea–onion (transplanted) and quality protein maize (raised bed)–fennel (raised bed) cropping sequence (39.23 and 36.69% respectively) over the existing soybean–wheat sequence. These might be owing to higher market price and higher value of total produce compared to existing cropping sequence. Direct seeded rice (long duration)–berseem (fodder) crop sequence had the lowest economic efficiency (₹348/ha/day) and relative economic efficiency (–15.43%) due to its lower system productivity compared to the existing cropping sequence. Samant (2015) reported that, the existing rice-based cropping system can be effectively diversified with inclusion of vegetables like brinjal, onion, tomato during the winter (*rabi*) season for higher system profitability and relative economic efficiency. Mishra *et al.,* (2007) also reported higher system profitability through inclusion of vegetable and pluses in rice-based cropping system.

Thus, it can be concluded that blackgram (broad bed) + DSR (furrow)–veg pea (broad bed) + coriander (furrow)–spring greengram proved more productive and remunerative cropping sequence, followed by sweet corn–field pea–onion (transplanted) and quality protein maize (raised bed)–fennel (raised bed) as diversified cropping sequences for better productivity, profitability and land-use efficiency than the existing soybean–wheat cropping system under south-eastern Rajasthan, India.

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