



## Relative efficiency of different cropping sequences in a farmers participatory research programme in semi-arid agro-ecosystem of Rajasthan

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### ABSTRACT

A farmers' participatory field experiment with seven crop sequences was conducted during 2002-07 in Tonk district of Rajasthan. The groundnut (*Arachis hypogaea* L.) – wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] and greengram [*Vigna radiata* (L.) Wilczek] - wheat crop sequences were found more productive and energy efficient than sorghum [*Sorghum bicolor* (L.) Moench] – chickpea (*Cicer arietinum* L.) and pearl millet [*Pennisetum glaucum* (L.) R. Br. Emend Stuntz] - chickpea cropping sequences. Groundnut-wheat (10.41 t/ha) crop sequence registered the 8.89, 16.90, 27.5 and 35.37 per cent higher Pearlmillet equivalent (PEs) than the greengram-wheat, greengram-barley (*Hordeum vulgare* L.), groundnut-mustard [*Brassica juncea* (L.) Czernj & Cosson] and pearl millet-wheat crop sequences, respectively. However, the maximum sustainable yield index (SYI) was recorded with pearl millet-wheat (0.91), followed by groundnut-wheat (0.88) and green gram-barley (0.79) crop sequence. Highest land-use efficiency (LUE) was obtained in groundnut-wheat system (72.05%) followed by pearl millet-wheat system (69.42%) and both were statistically at par, whereas the lowest LUE was recorded in greengram-barley (55.89%) cropping system. As regards production efficiency (PE) greengram-wheat greengram-barley and groundnut-wheat crop sequences were at par. Groundnut-wheat crop sequences registered significantly higher energy output over all other cropping sequences. The energy produced by groundnut-wheat was 13.06, 15.31 and 19.19 per cent higher than pearl millet-wheat, greengram-barley and greengram-wheat cropping sequences respectively. Sorghum-chickpea crop sequence was significantly more energy intensive than other cropping sequences. Groundnut-wheat and greengram-wheat were at par and recorded net returns of ₹37,806 and ₹33,104/ha, B:C ratio of 2.22 and 2.07 and economic efficiency of ₹ 143.5 and ₹153.4/ha/day, respectively. Sorghum-chickpea cropping system registered the lowest net returns (₹2143/ha), B:C ratio (1.12) and economic efficiency (₹9.6/ha/day). The soil health was not affected much by different cropping sequences but mean soil nutrient balance (NPK) was found positive with all the cropping sequences.

**Key words :** Cropping sequence, Energy efficiency, Production potential, Resource-use efficiency, Semi-arid agro-ecosystem, Soil health, Sustainability

In the era of shrinking resource base of land, water and energy, resource-use efficiency has become an important issue for considering the suitability of a cropping system (Yadav, 2002). Cropping systems of a region are decided by and large, by a number of soil and climatic parameters which determine overall agro-ecological setting for nourishment and appropriateness of a crop or a set of crops for cultivation. Nevertheless, at farmers' level, potential productivity and monetary benefits act as guiding principles while opting for a particular crop/cropping system. These decisions with respect to choice of crops and cropping systems are further narrowed down under influence of several other forces related to infrastructure facilities, socio-economic factors and technological developments,

all operating interactively at micro-level. Pearl millet, greengram, groundnut and sorghum based cropping systems are followed in the semi-arid regions of Rajasthan and their suitability/practicability and productivity depends upon the rainfall, temperature, conserved moisture, irrigation facilities and other resources at the farmers level. The pearl millet-wheat is one of the most important conventional cropping systems of arid and semi-arid eco-region of North-west India. In pearl millet-wheat system, farmers are now realizing the need to replace pearl millet with a more remunerative crops. Therefore, diversification may prove to be of paramount importance in several farming situations to improve productivity and profitability without deteriorating soil health for a sustainable agriculture.

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In Rajasthan, most of the pulses and oilseeds are grown under semi-arid agro-ecosystem, where harsh and unfavorable climatic conditions result in low productivity. Over the past decade, the role of agricultural research and development has moved beyond offering definitive, generally applicable packages of advice and recommendations on a 'take it' or 'leave it' basis. In many cases scientists and extension professionals simply do not have definitive answers for the problems being faced by those who have the responsibility for making sound agricultural decisions in an uncertain and ever-changing environment. These challenges, in turn, provide the basis for a new era in agricultural research and development, whereby researchers, farmers and extension professionals can learn together how to best manage the agriculture in a sustainable manner. So far, in the process of technology assessment farmers' participation along with their resources, social and economic aspects as well as their perception were often ignored particularly in case of the resource poor farmers. As a result productivity of cropping systems remains far behind the actual potential. Hence choice of the component crops in the cropping system representing a specific agro-ecological region needs to be suitably maneuvered to harvest the synergism among them towards efficient utilization of resource base and to increase overall productivity and profitability.

Realizing this, participatory research was conducted to assess the crop productivity, resource efficiency and profitability at farmers' fields representing semi-arid agro-ecosystem of Rajasthan. Farmer's participatory research (FPR) approach emphasizes processes that enable a local farmer in evolving and promoting improved agricultural technologies to the field. FPR refers to the active involvement and participation of farmers and other stakeholders in agricultural research. It values scientists' and farmers' knowledge equally and underlines the complementary nature of both pools of knowledge in generating and using technologies. This also helps in the widespread adoption of identified /relevant new practices and new varieties as a result of farmer-to-farmer extension. As a complement to conventional on-station research, FPR improves the overall quality of the agricultural research process. The specific objectives of the present study were to assess the sustainability, productivity and energy efficiency of different cropping systems in the semi-arid regions to increase food production and farmers' income at the farm level through farmer's participatory approach.

## MATERIALS AND METHODS

A field experiment was conducted at farmers' fields in an adopted village 'Soda' of Central Sheep and Wool Research Institute, Avikanagar during 2002-2007. The village

lies between 26° 15' to 26° 25' N latitude and 75° 25' to 75° 28' E longitude with an altitude of 326 m above mean sea level in semi-arid tract of Tonk district of Rajasthan. On farm trials were conducted over the years on the farmers' fields in order to assess the productivity and profitability of seven prominent crop sequences of the semi-arid region. These crop sequences were; pearl millet-chickpea; pearl millet-wheat; greengram-wheat; greengram-barley; groundnut-mustard; groundnut-wheat and sorghum-chickpea. The varieties used were; 'ICMH 356' of pearl millet, 'GNG 63' of chickpea, 'RAJ 3077' of wheat, 'K 851' of greengram, 'RD 2503' of barley, 'Somnath' of groundnut, 'Bio-902' of mustard, 'CSH 14' of sorghum. The *kharif* season crops were sown with the onset of monsoon and *rabi* season crops were sown at normal sowing time for respective crops. Mustard and chickpea were sown on conserved moisture, whereas wheat and barley were sown after applying pre-sowing irrigation. Water being scarce and limited resource, only limited crops (wheat and barley) were sown with irrigation water. Life saving irrigation was also given to the crops as and when required. Recommended doses of N, P and K were applied to different crops through urea, diammonium phosphate and muriate of potash, respectively. Crop sowing window period, number of irrigations at different crop growth stages and fertilizer dose of the different crops under all crop sequences are given in Table-1. There was a narrow variation in the values for different soil properties of the experimental fields and the average values as well as ranges were: pH 7.70 (7.52-7.98), EC-0.27 (0.21-0.30) dS m<sup>-1</sup>, organic carbon-0.31% (0.22-0.39), and available 154.47 (121.8-181.0 kg/ha), available P 16.70 (12.0-19.2 kg/ha) and available K 211.93 (197.5-239.3 kg/ha). The area received an annual rainfall of 162.8, 473.3, 404.5, 368.6 and 211.6 mm in the year 2002, 2003, 2004, 2005 and 2006, respectively. Each cropping sequence was grown at three farmers' field and each farmers' field was considered as a replication and thus for seven cropping sequences, a total of twenty one farmers were selected. The experiments were conducted at same site during the entire period of study. The need based plant protection measures were adopted in different crops. Observations on yield were recorded and analyzed statistically by Gomez and Gomez (1984). The economic yield of the component crops was taken into account over the years and then averaged and expressed as productivity (t/ha) of different cropping sequences. The cost of cultivation was calculated by taking in to account the prevailing prices of inputs. The minimum support prices were used for the grains of pearl millet, greengram, groundnut, sorghum, chickpea, wheat, barley and mustard, whereas prevailing local market prices were taken in to consideration for their straw.

The monetary return was calculated on yearly basis. Different crop sequences were compared by converting the yields of all the crops in a sequence into pearl millet equivalents (PEs) on prevailing market price basis. The sustainability of the system was measured by sustainable yield index (SYI), and was calculated as per the procedure described by Singh *et al.* (1990). For assessing the economic viability of the system, land use efficiency (LUE) was calculated from total duration of crops in the cropping system divided by 365. To compare the different crop sequences, the yields of all the crops were converted into PEs on price basis (Verma and Mudgal, 1983). Production efficiency in terms of kg/ha/day was worked out by total economic yield in terms of PE in a crop rotation divided by total duration of crops in a system (Tomar and Tiwari, 1990). Economic efficiency in terms of ₹/ha/day was worked out by dividing the net returns of the sequence by total duration of crops in a system in an agricultural year (Patil *et al.* 1995). Net returns were the difference between the gross returns of a system and total cost of cultivation of the component crops. B:C ratio (Returns per ₹ invested) of a system was expressed as net returns (₹) per ₹ spent. The energy output of different cropping sequences was calculated on the basis of economic yield as given by Mittal and Dhawan (1988) and expressed as total energy (MJ/ha). Economic efficiency was calculated by taking net returns into account and energy intensiveness was expressed as energy output of a system in MJ per ₹ invested.

## RESULTS AND DISCUSSION

### *Productivity of component crops*

The yield of all the *kharif* season crops were low during 2002-03 and 2006-07 as compared to other years because of the low rainfall (162.8 and 211.6 mm, respectively). The higher yields of pearl millet (2.24 t/ha), greengram (1.79 t/ha), groundnut (1.60 t/ha) and sorghum (1.99 t/ha) were recorded in 2004-05 (Table 2). The highest yield of wheat (5.76 t/ha in 2003-04) was recorded in groundnut-wheat sequence as compared to other cropping systems because groundnut being a legume fixes the atmospheric nitrogen and it sheds the leaves which are a rich source of plant nutrients. The higher yield of chickpea on average was recorded in pearl millet-chickpea system in comparison to sorghum-chickpea system. The mustard yields were higher by (87, 105 and 65 % in 2003-04, 2004-05 and 2005-06) in comparison to 2002-03 and 64, 80 and 45 % in 2003-04, 2004-05 and 2005-06 in comparison to 2006-07, respectively because of higher rainfall received during the monsoon season as well as one or two showers during *rabi* season in the month of January. Similar results were also reported by Mann and Jat (2007).

### *Pearlmillet equivalents (PEs)*

System productivity in terms of pearl millet-equivalent yield (PEs) and profitability played a vital role in determining the most productive and profitable cropping sequence. The pooled analysis of different cropping sequences revealed that groundnut-wheat (10.41 t/ha) produced the highest PEs, which was significantly higher than the other crop sequences and was followed by greengram-wheat (9.56 t/ha), greengram-barley (8.58 t/ha) and pearl millet-wheat (7.69 t/ha) crop sequences (Table 3). Groundnut-wheat crop sequence registered 8.89, 21.33, 40.11 and 35.37 per cent higher PEs than the greengram-wheat, greengram-barley, groundnut-mustard and pearl millet-wheat crop sequences, respectively. Kumpawat (2001) also reported similar results. In general, winter crops determined the PEs differences of the systems, because the yields from *kharif* crops were more or less same. Pearl millet-chickpea and sorghum-chickpea crop sequences registered minimum PEs (3.64 and 3.07 t/ha, respectively) because of relatively lower yields of chickpea compared with other crops.

### *Sustainability*

Ability of a system to sustain its productive performance over a period of time is expressed as sustainability. Pearl millet-wheat system expressed the highest sustainable yield index (SYI) of 0.91 (Table 3) and supports the current practice. Highest SYI for pearl millet-wheat crop sequence pointed to long term profitability for the farmers (Singh *et al.*, 1990). The lowest SYI was observed with groundnut-mustard cropping system (0.53) because yield of both the crops is highly influenced by rainfall received.

### *Resource-use efficiency*

The highest land-use efficiency (LUE) was obtained in groundnut-wheat system (72.1%) followed by pearl millet-wheat system (69.4%) and both were statistically at par (Table 4). The lowest LUE was recorded in greengram-barley cropping system (55.9%) followed by pearl millet-chickpea (58.4%) and greengram-wheat (58.9%) cropping system. The higher land-use efficiency suggests longer duration of crops in a calendar year. Kumpawat (2001) also reported the highest LUE (70%) in groundnut-wheat sequence at Bhilwara, Rajasthan. On the contrary production efficiency (PE) was the highest in greengram-wheat (44.4 kg PE/ha/day), closely followed by greengram-barley (42.0 kg PE/ha/day) crop sequence and the lowest in sorghum-chickpea (14.0 kg PE/ha/day), followed by pearl millet-chickpea (17.1 kg PE/ha/day) crop sequence. As regards, PE, greengram-wheat, greengram-barley and groundnut-wheat but significantly higher over other crop-

**Table 1.** Crop sowing window, number of irrigations and fertilizer dose of the different crops of the crop sequences.

Cropping sequences	Treatments	Years of experimentation											
		2002-03		2003-04		2004-05		2005-06		2006-07			
		Khariif	Rabi	Khariif	Rabi	Khariif	Rabi	Khariif	Rabi	Khariif	Rabi		
Pearlmillet-chickpea	Sowing window No. of irrigations	Last week of June One	First week of July Nil	Last week of June Nil	Middle of October Nil	Last week of June Nil	First week of October Nil	Last week of June Nil	Middle of October Nil	First week of October Nil	Last week of September One		
	Fertilizer dose	60+40+20	20+40+20	60+40+20	20+40+20	60+40+20	20+40+20	60+40+20	20+40+20	60+40+20	20+40+20	20+40+20	
Pearlmillet-wheat	Sowing window No. of irrigations	Last week of June One	First week of July Nil	Last week of June Nil	Middle of November Five	Last week of June Nil	Middle of November Five	Last week of June Nil	Middle of November Five	Middle of November One	Middle of November Five		
	Fertilizer dose	60+40+20	100+60+40	60+40+20	100+60+40	60+40+20	100+60+40	60+40+20	100+60+40	60+40+20	100+60+40		
Greengram-wheat	Sowing window No. of irrigations	First week of August Nil	Middle of November Five	Last week of June Nil	Middle of November Five	Last week of June Nil	Middle of November Five	Last week of June Nil	Middle of November Five	Middle of November Nil	Middle of November Five		
	Fertilizer dose	20+40+00	120+60+40	20+40+00	100+60+40	20+40+00	100+60+40	20+40+00	100+60+40	20+40+00	100+60+40		
Greengram-barley	Sowing window No. of irrigations	First week of August Nil	Middle of October Three	Last week of June Nil	Middle of October Three	Last week of June Nil	Middle of October Three	Last week of June Nil	Middle of October Three	Middle of October Nil	Middle of October Three		
	Fertilizer dose	20+40+00	50+20+20	20+40+00	50+20+20	20+40+00	50+20+20	20+40+00	50+20+20	20+40+00	50+20+20		
Groundnut-mustard	Sowing window No. of irrigations	First week of August one	Last week of October One	Last week of June Nil	First week of October Nil	Last week of June Nil	First week of October Nil	Last week of June one	Last week of September Nil	Middle of October Nil	Middle of October One		
	Fertilizer dose	20+40+20	30+20+20	20+40+20	30+20+20	20+40+20	30+20+20	20+40+20	30+20+20	20+40+20	30+20+20		
Groundnut-wheat	Sowing window No. of irrigations	First week of August one	Middle of November Five	Last week of June Nil	Middle of November Five	Last week of June One	Middle of November Five	Last week of June One	Middle of November Nil	Middle of November Nil	Middle of November Five		
	Fertilizer dose	20+40+20	100+60+40	20+40+20	100+60+40	20+40+20	100+60+40	20+40+20	100+60+40	20+40+20	100+60+40		

Five irrigations at CRI, Tillering, Jointing, Flowering and Milking crop growth stages; Three irrigations at Tillering, Flowering and Milking crop growth stages; One irrigation as life saving irrigation

Table 1. Continued...

Cropping sequences	Treatments	Years of experimentation											
		2002-03		2003-04		2004-05		2005-06		2006-07			
		Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi		
Sorghum-chickpea	Sowing window No. of irrigations Fertilizer dose	Last week of June Nil 40+20+20	Last week of September One 20+40+20	First week of July Nil 40+20+20	First week of October Nil 40+20+20	Last week of June Nil 20+40+20	Middle of October Nil 40+20+20	Last week of June Nil 40+20+20	First week of October Nil 20+40+20	Middle of July Nil 40+20+20	First week of October Nil 20+40+20	Middle of July Nil 40+20+20	Last week of September One 20+40+20

Five irrigations atCRI, Tillering, Jointing, Flowering and Milking crop growth stages; Three irrigations at Tillering, Flowering and Milking crop growth stages; One irrigation as life saving irrigation

ping systems. Growing of wheat in succession to pulse (green gram) or oilseed (groundnut) crop, resulted in the highest PE of the cropping system.

**Energy efficiency**

Groundnut-wheat crop sequence registered the maximum energy output (1,09,052 MJ/ha) and it was significantly higher than all other cropping sequences under investigation (Table 4). This was due to relatively higher energy equivalent for groundnut, i.e., 25 MJ/ kg dry biomass (Devasenapathy *et al.*, 2009) and yield of crops being comparable with other cropping systems. The energy produced by groundnut-wheat sequence was 13.06, 15.31 and 19.19 per cent higher than pearl millet-wheat (94,809 MJ/ha), greengram-barley (92,354 MJ/ha) and greengram-wheat (88,127 MJ/ha) cropping sequences, respectively. The energy intensiveness of different cropping sequences revealed that the highest value was observed with sorghum-chickpea (13.13 MJ/₹) crop sequence and it was significantly higher over other cropping sequences. The minimum values pertaining to energy intensiveness was recorded in greengram-wheat (2.66 MJ/₹) and groundnut-wheat (2.88 MJ/₹) crop sequence. This was due to the lower productivity and net returns of the cropping systems. Lower energy intensiveness results in higher productive and resource efficient cropping sequence.

**Economics**

The economic analysis of different crop sequences showed that groundnut-wheat registered the highest net returns (₹37,806/ha) and benefit: cost ratio (B:C ratio)/ returns per ₹ invested (₹2.22), whereas sorghum-chickpea registered the lowest net returns (₹ 2,143/ha) and B:C ratio (1.12). Groundnut-wheat and greengram-wheat crop sequences recorded at par net returns, which were significantly higher than all the cropping sequences under study except pearl millet-wheat and greengram-barley crop sequence (Table 4). This was mainly due to inclusion of pulse (greengram) and oilseed (groundnut) crop in the system. The B:C ratio were significantly at par in pearl millet-wheat (₹1.86), greengram-wheat (₹2.07), greengram-barley (₹1.93), groundnut-mustard (₹2.05) and groundnut-wheat (₹2.22) crop sequences. This was due to higher gross returns and moderate cost of cultivation of the above systems. The highest economic efficiency was recorded with the greengram-wheat (₹153.4/ha/day) and it was at par with groundnut-wheat (₹143.5/ha/day) and greengram-barley (₹128.2/ha/day) crop sequence. The minimum economic efficiency was recorded with the sorghum-chickpea (₹9.6/ha/day) crop sequence, followed by pearl millet-chickpea (₹26.2/ha/day) crop sequence. The lower economic efficiency was attributed due to the lower yield and net returns.

**Soil health**

The mean values of pH, EC, bulk density and organic carbon

**Table 2.** Economic yield of crops under different cropping sequences.

Cropping sequence	Economic yield (t/ha)									
	2002-03		2003-04		2004-05		2005-06		2006-07	
	<i>kharif</i>	<i>rabi</i>	<i>kharif</i>	<i>rabi</i>	<i>kharif</i>	<i>rabi</i>	<i>kharif</i>	<i>rabi</i>	<i>kharif</i>	<i>rabi</i>
Pearlmillet-chickpea	1.98	0.46	2.00	0.65	2.24	0.70	1.94	0.62	2.08	0.52
Pearlmillet-wheat	1.80	4.25	1.95	4.43	2.32	4.57	1.90	4.63	1.96	4.43
Greengram-wheat	0.70	4.97	1.59	4.26	1.79	4.89	1.44	4.72	0.81	4.82
Greengram-barley	0.70	5.21	1.48	5.28	1.54	5.03	1.38	4.97	0.82	5.02
Groundnut-mustard	0.76	0.86	1.35	1.61	1.36	1.76	1.26	1.42	0.96	0.98
Groundnut-wheat	1.07	4.54	1.59	5.76	1.60	4.82	1.49	5.32	1.32	4.62
Sorghum-chickpea	1.12	0.49	1.86	0.61	1.99	0.53	1.68	0.59	1.26	0.56

**Table 3.** Pearl millet equivalents (PEs) and sustainable yield index of different crops.

Cropping sequence	Pearlmillet Equivalents (t/ha)						Sustainable yield index (SYI)
	2002-03	2003-04	2004-05	2005-06	2006-07	Pooled over five years	
Pearlmillet-chickpea	3.11	3.80	4.18	3.63	3.47	3.64	0.78
Pearlmillet-wheat	7.21	7.48	8.00	7.63	8.11	7.69	0.91
Greengram-wheat	8.20	9.62	10.97	10.01	8.97	9.56	0.78
Greengram-barley	7.20	9.49	9.48	9.19	7.56	8.58	0.79
Groundnut-mustard	4.42	8.84	9.77	8.29	5.81	7.43	0.53
Groundnut-wheat	8.76	11.60	10.65	10.89	10.14	10.41	0.81
Sorghum-chickpea	2.32	3.56	3.44	3.29	2.76	3.07	0.72
SEm±	0.29	0.45	0.48	0.33	0.43	0.21	
CD (P=0.05)	0.91	1.40	1.48	1.02	1.31	0.51	

**Table 4.** Resource-use efficiency, energy efficiency and economics of different cropping sequences (Pooled over 5 years).

Cropping sequence	Resource-use efficiency		Energy efficiency		Economics		
	Land use efficiency (%)	Production efficiency (kg PE/ha/day)	Total energy (x 10 <sup>3</sup> MJ/ha)	Energy intensiveness (MJ/₹)	Net returns (x ₹10 <sup>3</sup> /ha)	B:C ratio	Economic efficiency (₹/ha/day)
	Pearlmillet-chickpea	58.4	17.1	38.79	6.92	5.60	1.24
Pearlmillet-wheat	69.4	30.4	94.81	3.52	26.91	1.86	106.2
Greengram-wheat	58.9	44.4	88.13	2.66	33.10	2.07	153.4
Greengram-barley	55.9	42.0	92.35	3.52	26.27	1.93	128.2
Groundnut-mustard	66.1	30.7	61.57	3.10	19.86	2.05	81.6
Groundnut-wheat	72.1	39.5	109.05	2.88	37.81	2.22	143.5
Sorghum-chickpea	60.2	14.0	28.14	13.13	2.14	1.12	9.6
SEm±	1.15	2.31	4.32	1.15	2.71	0.13	11.01
CD (P= 0.05)	3.54	7.14	13.32	3.55	8.36	0.38	33.94

**Table 5.** Physico-chemical properties of soil before and after experiment

Cropping sequences	pH (1:2)		EC (dS/m)		BD (g/cc)		OC (%)	
	Before	After	Before	After	Before	After	Before	After
	Pearlmillet-chickpea	7.52	7.45	0.21	0.24	1.41	1.42	0.34
Pearlmillet-wheat	7.77	7.85	0.26	0.25	1.46	1.41	0.33	0.32
Greengram-wheat	7.58	7.55	0.27	0.24	1.44	1.45	0.22	0.26
Greengram-barley	7.60	7.65	0.27	0.27	1.51	1.49	0.28	0.29
Groundnut-mustard	7.98	7.85	0.30	0.25	1.48	1.50	0.34	0.33
Groundnut-wheat	7.82	7.80	0.28	0.23	1.46	1.47	0.29	0.30
Sorghum-chickpea	7.65	7.65	0.27	0.24	1.50	1.46	0.39	0.37
Mean	7.70	7.69	0.27	0.25	1.47	1.46	0.31	0.32

**Table 6.** Effect of different cropping sequences on soil health parameters before and after experiment

Cropping sequences	Available N (kg/ha)		Available P (kg/ha)		Available K (kg/ha)		Available Fe (ppm)		Available Zn (ppm)	
	Before	After	Before	After	Before	After	Before	After	Before	After
Pearlmillet-chickpea	150.4	162.0	17.5	17.8	210.5	217.2	8.26	8.30	1.58	1.41
Pearlmillet-wheat	161.3	153.5	18.2	19.2	222.6	234.8	8.01	7.93	1.65	1.33
Greengram-wheat	121.8	129.5	15.9	16.1	200.5	198.4	9.50	9.76	1.47	1.87
Greengram-barley	146.4	148.5	16.3	15.6	212.8	223.4	9.00	9.23	1.55	1.17
Groundnut-mustard	139.9	154.0	12.0	12.9	239.3	241.7	8.04	7.44	1.39	1.49
Groundnut-wheat	180.5	192.5	17.8	18.5	197.5	189.4	9.30	9.29	1.60	1.58
Sorghum-chickpea	181.0	189.0	19.2	18.0	200.3	211.6	7.99	8.12	1.72	1.72
Mean	154.5	161.3	16.7	16.9	211.9	216.6	8.59	8.58	1.57	1.51

were almost similar before and after the experiment on cropping sequences. After the end of experiment, the mean nutrient balance (NPK) was found positive with respect to different cropping sequences, however, micronutrient (Fe & Zn) balance was found negative. Groundnut-mustard cropping sequence recorded higher values of pH and bulk density, whereas greengram-barley recorded highest value of EC (Table 5). Sorghum-chickpea had highest value of organic carbon followed by pearlmillet-chickpea. Pearlmillet-wheat cropping sequence had lowest bulk density, which is good symbol of soil aeration. The organic carbon, available N, P and K content in the soil is a good indicator of soil health. The lowest OC percentage and nitrogen was recorded under greengram-wheat sequence which may be due to more uptake of nitrogen by the wheat crop (Table 6). The highest available nitrogen was recorded under groundnut-wheat sequence which may be due to addition of more biologically fixed nitrogen in soil than other cropping sequences. The similar result was also reported by Dhiman (2010). The highest available P and K in the soil were under pearl millet-wheat cropping sequence than other sequences. The lowest available K was recorded under groundnut-wheat sequence which may be due to more uptake of K by wheat and groundnut. The highest available Fe and Zn content in the soil after cropping sequence were recorded under greengram-wheat, whereas lowest available Fe content was recorded with groundnut- mustard. Green gram-barley cropping sequence recorded the lowest available Zn content in the soil than other cropping sequences.

Among the different cropping sequences the groundnut-wheat crop sequence was found to be the best sequence based on the productivity, profitability and energy yield followed by greengram-wheat than the conventional pearlmillet-wheat sequence. However, based on the sustainability, energy yield and economic viability, pearlmillet-wheat crop sequence recorded the highest SYI and was at par with greengram-wheat crop sequence in respect of net returns. Soil health was not much affected

by the influence of different cropping sequences but it was better with groundnut-wheat and greengram-wheat crop sequences. In general, groundnut-wheat and greengram-wheat crop sequences were found to be biologically efficient and economically profitable alternative to conventional pearlmillet-wheat crop sequence for semi-arid ecosystem of Rajasthan.

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