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Diversification of rice (*Oryza sativa* L.)-based cropping systems for higher productivity, resource-use efficiency and economic returns in south Gujarat, India

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The continuous growing of rice has led to a deterioration in soil quality, resulting in a serious threat to agricultural sustainability in the high rainfall zone of south Gujarat, India. Therefore, crop diversification with a wider choice in the production of crop varieties is being promoted to restore the soil quality. A field experiment was conducted in Navsari, India during 2003–2007 on a Vertisol to evaluate the productivity, sustainability, resource-use efficiency and economics of 10 rice-based cropping systems. The results showed that system productivity for rice–fenugreek (*Trigonella foenum-graecum*)–okra (*Abelmoschus esculentus*) was highest (25.73 t ha^{-1}), followed by rice–onion (*Allium cepa*)–cowpea (*Vigna sinensis* L.) (24.15 t ha^{-1}); and the lowest system productivity was observed with the rice–wheat (*Triticum aestivum*)–fallow system (7.85 t ha^{-1}). The sustainable yield index (0.97), production efficiency (102.94 kg ha^{-1} day^{-1}) and field water use efficiency (15.98 kg ha^{-1} mm^{-1}) were maximum with the rice–fenugreek–okra system. Similarly, net return (96,286 Rs ha^{-1}), net return per rupee invested (2.83 Rs), monetary production efficiency (385.14 Rs ha^{-1} day^{-1}) and water use efficiency (59.80 Rs ha^{-1} mm^{-1}) were maximum with the rice–fenugreek–okra cropping sequence. There were significant effects of various cropping sequences on available nitrogen, phosphorus, potassium and organic carbon content in the soil. Overall, the rice–fenugreek–okra system was found to be the most productive, sustainable, resource-use efficient and remunerative cropping system, followed by the rice–onion–cowpea system.

Keywords: crop diversification; resource-use efficiency; rice-equivalent yield; sustainability

Introduction

Rice is the dominant rainy season crop on Vertisols (deep black soil) of south Gujarat, India. However, continuous cultivation of rice for longer periods, and often under poor soil and crop management practices, results in the loss of soil fertility as indicated by the emergence of multi-nutrient deficiencies (Fujisaka et al. 1994; J Singh and JP Singh 1995; Dwivedi et al. 2001) and deterioration of soil physical properties (Tripathi, 1992). This decline in soil quality results in a decrease in factor productivity

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and overall crop productivity (RL Yadav 1998). Cassman et al. (1995) and Olk and Cassman (1995) proposed that the relatively low response to nitrogen (N) fertilizers in continuously flooded rice systems was associated with sequestration of N as recalcitrant N compounds that have slow mineralization rates; these N complexes are formed as a result of slow and incomplete decomposition of retained rice crop residues. If this is the case, then there is perhaps a need to include upland crops such as wheat and grain legumes in rice-based rotations to enhance the decomposition of accumulated organic matter under aerobic conditions (in the presence of oxygen the decomposition of organic matter is faster) compared with the slow rate of organic matter decomposition in continuously waterlogged rice soils (Sahrawat 2004). Thus, crop diversification, in which lowland rice is grown in rotation with upland crops including legumes, has the potential to alleviate the above-stated problems. Moreover, such crop diversification would fulfill the basic needs of cereals, pulses, oilseeds and vegetables, and regulate farm income by better withstanding weather aberrations, controlling price fluctuations, ensuring a balanced food supply, conserving natural resources, reducing chemical fertilizer and pesticide loads, ensuring environmental safety and creating employment opportunities (Gill and Ahlawat 2006). In the era of a shrinking land resource base, water and energy resource use efficiency are important for the suitability of a cropping system (JSP Yadav 2002). Hence, the selection of crops needs to be planned to utilize the synergism among crops towards the efficient utilization of resources and to increase overall productivity (Anderson 2005). Because of high rainfall (an average annual rainfall of $\sim$1900 mm), mainly during June–September (rainy season), frequent flooding with run-off water from upstream, Vertisols with low usability under wet conditions and weed menace, and the use of rice as a staple food for the people in this region, rice cannot be replaced with other crops during the rainy season. Hence, the only viable option is to include suitable crops during the post-rainy (November to February) and summer (March to May) seasons. Growing of crops such as vegetables, pulses and oilseeds during the post-rainy season is an alternative approach for realizing overall higher productivity and profitability (Newaj and Yadav 1992). The inclusion of such crops along with fodder crops will help to improve the economic situation of small and marginal farmers because of the higher income from such crops (AK Sharma et al. 2007). Moreover, cultivation of such crops during the post-rainy season allows the efficient utilization of irrigation water, labor and other inputs for higher productivity, profitability and food security (Satyasai and Viswanathan 1996). Similarly, grain legumes and vegetables can be introduced during the summer season. However, the available growing period after harvest of the post-rainy season crop and before sowing rainy season rice is short (50–70 days), and occasional pre-monsoon showers may promote disease incidence or damage or destroy the harvest. High yielding, short-duration and disease-resistant grain legumes and vegetable crops have the best chance of acceptance by farmers for their ability to fit into the existing rice-based system and maintain or improve the short- and long-term productivity and economic viability of the system. Cowpea, groundnut (*Arachis hypogea*) and green gram (*Vigna radiata*) are potential grain legumes for this region. Hence, efforts are being made to promote the diversification of the rice-based cropping sequence in this zone of the country to sustain agricultural productivity and fulfill demand for vegetables, pulses, oilseeds and fodder. Therefore, this study was carried out to determine the most productive, resource-use-efficient, remunerative and sustainable cropping system for irrigated south Gujarat region in India.

Materials and methods

A field experiment was conducted at the All India Coordinated Research Project (AICRP) on the Cropping System Research Farm at Navsari Agricultural University, Navsari, India during 2003–2007 using the same site and layout. The experimental soil was Vertisol (Ustocrepts, Jalalpur; 66.25% clay), alkaline in reaction (pH 7.8), low in available N (213.0 kg ha^{-1}), medium in available P (41.30 kg ha^{-1}) and high in available K (363.23 kg ha^{-1}). The region enjoys a predominantly maritime climate; being situated 15 km east of the Arabian Sea coast. The climate is humid and diurnal and the seasonal variation in temperature remains within a narrow range (the average minimum temperature of the coldest month, January, was 14.4°C, whereas the average maximum temperature of warmest month, April, was 35.1°C). Ten different cropping sequences were tried in a randomized block design (RBD) with three replications.

They were: T_1, rice–wheat–fallow; T_2, rice–wheat–green gram; T_3, rice–sorghum (*Sorghum bicolor*)–green gram; T_4, rice–castor (*Ricinus communis*); T_5, rice–mustard (*Brassica juncea*)–green gram; T_6, rice–sorghum–groundnut (*Arachis hypogea*); T_7, rice–chickpea (*Cicer arietinum*)–cowpea; T_8, rice–fenugreek–okra; T_9, rice–onion–cowpea; T_{10}, rice–chickpea–sesamum (*Sesamum indicum*).

In the case of T_4, the summer crop could not be grown because of the long duration of the castor crop. The varieties of different crops used were: rice 'GR-3', wheat 'GW-496', green gram 'K-851', fodder sorghum 'local variety', castor 'GCH-4', mustard 'GM-2', groundnut 'GG-2', chickpea 'ICCC-4', cowpea 'pusa phalguni', fenugreek 'local variety', okra 'parbhani kranti', sesamum 'GT-1' and onion 'Nasik red'. The gross plot size was 6.3 × 6.0 m.

In the rainy season, 25-day-old rice seedlings were transplanted manually in field during first week of July and the crop was harvested in the third week of October. The subsequent post-rainy season crops were sown by hand during the second half of November, except in the case of onion for which 25-day-old seedlings were transplanted during mid December. Summer season crops were sown manually after harvest of the preceding post-rainy season crops in March, except for okra, which was sown during second half of January. To reduce water loss through deep percolation and seepage in the rice crop, an impervious soil layer was created in the subsurface by puddling with 4–5 cross-cultivations of the land with 5 cm deep water, followed by leveling and bunding of the field. Just after harvest of the rice crop, the plots were irrigated and prepared for sowing of the ensuing post-rainy season crops using two cross-cultivation and two harrowing operations, followed by planking with a wooden beam attached behind the tractor to reduce clod size. For summer season crops, field preparation included one deep plowing using a mold board plogh, followed by two harrowing operations and planking. Spacing and seed rate maintained for various crops were: rice (20 × 15 cm and 25 kg ha^{-1}), wheat (22.5 cm and 120 kg ha^{-1}), fodder sorghum (30 × 8 cm and 30 kg ha^{-1}), castor (90 × 60 cm and 6 kg ha^{-1}), mustard (45 × 15 and 4 kg ha^{-1}), chickpea (30 × 10 cm and 60 kg ha^{-1}), fenugreek (broadcasting and 40 kg ha^{-1}), onion (15 × 10 cm and 10 kg ha^{-1}), greengram (30 × 10 cm and 25 kg ha^{-1}), groundnut (30 × 10 cm and 120 kg ha^{-1}), cowpea (30 × 10 cm and 30 kg ha^{-1}), okra (30 × 10 cm and 10 kg ha^{-1}) and sesamum (45 × 10 cm and 2.5 kg ha^{-1}), respectively. Crops were fertilized with the recommended dose of N, P_2O_5 and K_2O (kg ha^{-1}): rice (100–50–0), wheat (120–60–0), sorghum (80–40–0), castor (75–50–0), mustard

(50–50–0), chickpea (20–40–0), fenugreek (25–0–0), onion (75–50–50), greengram (20–40–0), groundnut (25–50–0), cowpea (20–40–0), okra (150–50–0) and sesamum (25–50–0). Potassium was not applied to any of the crops because the soil was high in available K, the exception was onion because K is known to improve the keeping quality of onion (Langenhoven 1999; Nabi et al. 2010). All of the P and K and a basal dose of N was drilled in rows 5–6 cm below seeds before sowing/planting of the crops; the remaining N was applied in split doses as per recommendations in the region for various crops. In rice, all of the P and K and a basal dose of N was given before puddling and incorporated in the soil. Urea (46.0% N) was used as source of N, single superphosphate (16.99% P_2O_5) for P and muriate of potash (KCl) (49.6% K_2O) for K.

The average annual rainfall (mm) and run-off loss as percentage of rain water during the years of the study were: 2433 and 54.79 (2003–2004), 2114 and 45.61 (2004–2005), 2583 and 61.29 (2005–2006), and 1919 and 37.47 (2006–2007), respectively. In rice, the entire water requirement of the crop was met through rainfall. The post-rainy and summer season crops were grown under irrigated conditions with canal or tube well water. No significant amount of rainfall was received during the post-rainy and summer cropping seasons in this study, which is a common feature in this part of India. In each irrigation, 5 cm water was applied by measuring with a parshall flume. Recommended interculturing practices were followed as and when required for successful cultivation of the various crops. In the post-rainy season, sorghum was grown as fodder, fenugreek as green leafy vegetable, onion as bulbs and remainder of the crops were grown as grain. In the summer season, green cowpea pods were harvested in 6 pickings and okra in 14 pickings for vegetable purpose. In sorghum, only one cutting was taken after 75 days of sowing. Fenugreek was harvested just above the ground surface 30 days after sowing using sickles. For ease in digging in groundnut and onion crops, irrigation was given 5–6 days before harvest of these crops. Economic yields of the component crops were converted to rice-equivalent yield (REY), taking into account the prevailing market price (Rs kg^{-1}) of rice (5.90), wheat (7.50), sorghum (0.70), castor (14.0), mustard (25.0), chickpea (16.0), fenugreek (5.50), onion (4.00), green gram (25.0), groundnut (15.0), cowpea (10.0), okra (10.0) and sesamum (30.0). The selling price (Rs kg^{-1}) of crop residues sold as cattle fodder was: rice and wheat (1.20), green gram (1.40), chickpea and groundnut (1.25) and cowpea (0.70). Total field duration of a cropping system expressed in percentage of 365 days was taken as the land use efficiency (LUE) of the system (Tomar and Tiwari 1990). Production efficiency was expressed as the ratio of system productivity (kg REY ha^{-1}) to total duration of the system in days (Patil et al. 1995). Water use efficiency (WUE) was computed by dividing system productivity with total amount of water applied in the system and was expressed as kg REY ha^{-1} mm^{-1} of water used. From a practical point of view for this study, the total amount of water applied included the irrigation water and stored rainwater (rainfall minus run-off loss). Monetary production efficiency and water use efficiency were calculated by taking net return (Rs ha^{-1}) instead of REY. The sustainable yield index (SYI) was calculated as per Guggari and Kalaghatagi (2004).

$$\mathrm{SYI} = \frac{\mathrm{Y}\text{-}\delta}{\mathrm{Y\ max}}$$

where Y, estimated mean yield; δ, estimated standard deviation; Y max, observed maximum yield in the experiment over the years.

Economic analysis

For economic evaluation of various rice-based cropping systems, averaged data of four crop cycles were used. The cost of cultivation of different crops was calculated based on the various operations performed and materials used for raising the crops. For rice and onion, the operations and materials used were seed, nursery raising and its maintenance, field preparation, transplanting, fertilizers and their application, weeding and herbicide application, irrigation, harvesting and threshing. In other crops the operations and materials used were seed, seed bed preparation, sowing, fertilizers and their application, weeding, irrigation, harvesting and threshing. The costs (in Indian rupees, 1 Rs = US $0.021) incurred were (Rs kg^{-1} seed): rice (13.20), wheat (15.00), green gram (40.0), sorghum (30.0), castor (100.0), mustard (40.0), chickpea (20.0), cowpea (20.0), fenugreek (25.0), groundnut (26.15), onion (150.0), okra (140.0) and sesamum (50.0) and, 5.20 Rs kg^{-1} of urea, 3.30 Rs kg^{-1} of single superphosphate, 4.66 Rs kg^{-1} of muriate of potash and 260 Rs l^{-1} of butachlor. Among field operations, the cost of plowing/harrowing was taken as 200 Rs ha^{-1}, labor 50 Rs day^{-1}, irrigation 120 Rs ha^{-1} and puddling 500 Rs ha^{-1}. Gross returns included income from sale of main product of all crops and straw/haulm in rice, wheat, green gram, groundnut, chickpea and cowpea. Net returns were the difference between the gross return of a system and the total cost of cultivation of the component crops in a cropping system. The data collected from the experiment were subjected to statistical test by following 'Analysis of variance technique' as suggested by Cochran and Cox (1957).

Results and discussion

Productivity of component crops

It was found that yield of component crops varied significantly with the cropping system. Rice yield was highest (5.12 t ha^{-1}) under the rice–onion–cowpea sequence compared with other sequences (Table 1). Cropping sequences that included legumes

Table 1. Economic and straw/haulm/stover yields of component crops, rice equivalent yield (REY) and sustainable yield index (SYI) of various rice-based cropping systems.

Cropping system	Economic yield (t ha^{-1})			Straw/haulm/ stover yield (t ha^{-1})			System productivity (REY t ha^{-1})	SYI
Rice–wheat–fallow	4.80	2.38	–	5.40	2.62	–	7.85	0.27
Rice–wheat–greengram	4.89	2.38	1.11	5.85	2.63	4.55	12.45	0.45
Rice–sorghum–greengram	4.74	23.58*	1.15	5.46	–	4.60	9.43	0.34
Rice–castor	4.73	2.11	–	5.33	–	–	9.72	0.35
Rice–mustard–greengram	4.75	0.84	1.09	5.42	3.75	4.45	12.79	0.47
Rice–sorghum–groundnut	4.74	21.77*	2.15	5.37	–	5.08	10.21	0.37
Rice–chickpea –cowpea	4.97	0.67	2.78**	5.55	1.40	12.10*	11.18	0.40
Rice–fenugreek–okra	4.88	8.04***	6.91	5.48	–	–	25.73	0.97
Rice–onion –cowpea	5.12	25.52	1.651**	5.76	–	11.40*	24.15	0.91
Rice–chickpea–sesamum	4.99	0.63	0.72	5.61	1.39	4.92	10.28	0.37
SEM ±							0.45	0.02
CD at (0.05)							1.29	0.06

Note: Mean of the four years of the study. *Green fodder yield, **green pod yield, ***green leaves yield.

performed fairly well with regard to rice productivity. Reports from various parts of India indicate that the inclusion of legumes in rice-based system increased the productivity of rice (Hegde 1992). Introduction of a legume crop in the rice-based cropping system may have advantages well beyond the N addition through biological nitrogen fixation including nutrient recycling from deeper soil layers, minimize soil compaction, organic matter inputs to soil, break the weed and pest cycles and minimize the possible harmful allelopathic effects (Sanford and Hairston 1984; Wani et al. 1995). The lowest rice yield was recorded under rice–castor sequence (4.73 t ha^{-1}). It might be due to the nutrient exhaustive nature of the castor crop (75–50–0 kg ha^{-1} of NPK), which might have adversely affected the growth and development of succeeding rice in the rotation. Similar results were also reported by Kumar et al. (2008) and Bastia et al. (2008) for rice-based cropping systems. Among the post-rainy season crops, wheat yield was the same under both rice–wheat–green gram and rice–wheat–fallow (2.38 t ha^{-1}) systems. However, wheat yield was lower compared with average wheat productivity (2.5 t ha^{-1}) under irrigation in Gujarat. This can be mainly attributed to the lack of suitable thermal requirements for wheat in south Gujarat. The optimal mean daily temperature of wheat at germination, tillering, accelerated growth and grain filling stages are 20–25, 16–20, 20–23 and 23–25°C, respectively, the mean daily temperature at experimental site during these stages was higher at 25, 22, 22 and 27°C, respectively (mean data during four years of study). Subsurface compaction caused by puddling reduces the root growth of wheat (Oussible et al. 1992; Aggarwal et al. 1995), which is also responsible for low wheat productivity when it follows the rice crop. The yield of sorghum was similar under rice–sorghum–green gram and rice–sorghum–groundnut sequences. Productivity of castor (2.11t ha^{-1}) was higher compared with the average productivity of castor in the state of Gujarat (1.92 t ha^{-1}). Productivity of mustard, chickpea and onion was lower compared with the average productivity of these crops (respectively, 1.13, 1.00 and 26.6 t ha^{-1}) in Gujarat (Anonymous 2009). The lower yield of mustard can be attributed to the high temperature during crop growth period leading to low/poor plant height, branching, leaf area, number of siliqua and test weight (data not given), which culminate in a lower crop yield. Chickpea requires a cloddy soil structure for better aeration but because of the clayey soil and disturbed soil structure due to puddling for the rice crop, proper seed bed preparation for the chickpea crop was not accomplished. Impaired soil structure, poor aeration, higher soil moisture content for an extended period in the plow layer due to puddling and continuous submergence during the preceding rice may have resulted in low crop stand, restricted root growth, poor nodulation (chickpea) and hence poor growth and yield of the post-rainy season crops like mustard and chickpea (Prasadini et al. 1993). Similar factors might be responsible for the lower yield of onion. Even though fenugreek performed well with respect to productivity, a yield comparison could not be made due to unavailability of the data from the state. Among the summer crops, the yield of green gram was higher under the rice–sorghum–green gram sequence (1.15 t ha^{-1}) than under rice–wheat–green gram (1.11 tha^{-1}) and rice–mustard–green gram (1.09 t ha^{-1}). Cowpea yield was higher in the rice–chickpea–cowpea sequence than in the rice–onion–cowpea sequence. Nutrient recycling from deeper layers by chickpea may benefit the succeeding cowpea compared with the shallow-rooted nutrient exhaustive onion (75–50–50 NPK kg ha^{-1}). The yields of groundnut and sesamum were higher than the average productivity of these crops in the state of Gujarat (1.82 and 0.35 t ha^{-1}, respectively). However, the productivity of okra was lower than the state average productivity (7.74 t ha^{-1}; Anonymous 2004) in Gujarat. Such variability in the yield of crops grown in various sequence systems might be attributed to several biological and environmental factors and their complex interactions (Francis 1989).

System productivity

System productivity as rice equivalent yield (REY ha^{-1}) was highest in rice–fenugreek–okra (25.73 t ha^{-1}; Table 1). This could mainly be attributed to the high price fetched by okra in the market, although its yield was lower than the average state productivity (6.91 t ha^{-1}). This was followed by the rice–onion–cowpea cropping sequence. In this system, onion contributed most (68.58%) to enhance the equivalent yield due to its higher marketable yield (25.52 t ha^{-1}). With the exception of onion, the summer season crops governed the REY of the systems, because the contribution of the post-rainy season crops was suboptimal. These results corroborate the findings of P Singh et al. (2007) who reported that rice–pea–okra, followed by rice–pea–onion, was the most productive cropping system for eastern Uttar Pradesh, India. Mishra et al. (2007) also reported higher productivity and profitability with the inclusion of vegetables and pulses in the rice-based cropping system. The contribution of the summer crops to REY in the rice–wheat–green gram, rice–sorghum–green gram, rice–mustard–green gram, rice–sorghum–groundnut, rice–chickpea–cowpea, rice–fenugreek–okra and rice–chickpea–sesamum systems was 37, 39, 36, 43, 41, 49 and 36%, respectively. The lowest REY (7.85 t ha^{-1}) was recorded under the rice–wheat–fallow system. This clearly shows the importance of summer crops to increase system productivity. Among the cropping sequences involving a summer crop, the lowest REY was recorded with the rice–sorghum–green gram and rice–sorghum–groundnut cropping systems. Fodder sorghum known for its allelopathic effects on the following crops might have adversely affected the productivity of succeeding crops in the rotation (Kim et al. 1993; Ben-Hammounda et al. 1995; Cheema 1998).

Sustainable yield index (SYI)

Rice–fenugreek–okra recorded the highest SYI of 0.97, followed by rice–onion–cowpea (0.91). This indicates that the minimum guaranteed yield obtained from these sequences is 97 and 91%, respectively, and they are less affected by seasonal variations. Furthermore, it can be seen that cropping sequences involving legumes recorded higher SYI values than those with nonlegumes. Legumes are known to offer special advantage regarding the stability of the system because of their effect on soil N balance and wider adaptability to diverse conditions (Bastia et al 2008). When used in cropping systems, it is often assumed that legumes will satisfy a large part of their own N requirement through biological N fixation (BNF), 'sparing' soil N compared with nonlegume crops, and this benefits the subsequent crops (Timsina and Connor 2001). The lowest SYI value was recorded under the rice–wheat sequence.

Resource-use efficiency

The rice–wheat–green gram and rice–sorghum–groundnut cropping sequences registered the highest land use efficiency (83.56% in both systems; Table 2). This can be

Table 2. Resource use efficiency and man days ha^{-1} generated under various rice-based cropping systems.

Cropping system	Land-use efficiency (%)	Production efficiency (kg REY $ha^{-1}day^{-1}$)	WUE (kg REY $ha^{-1}mm^{-1}$)	Man-days ha^{-1} $year^{-1}$	Economic efficiency: Production efficiency (Rs ha^{-1} day^{-1})	Economic efficiency: WUE (Rs ha^{-1} mm^{-1})
Rice–wheat–fallow	63.01	34.17	5.56	321	88.90	14.50
Rice–wheat – greengram	83.56	40.83	7.28	397	156.19	27.85
Rice–sorghum–greengram	71.23	36.30	5.85	386	173.42	28.00
Rice–castor	72.60	36.68	6.89	338	107.47	20.19
Rice–mustard–greengram	76.71	45.69	7.70	399	172.91	29.16
Rice–sorghum–groundnut	83.56	33.48	6.15	414	140.38	25.79
Rice–chickpea – cowpea	78.08	39.24	6.94	403	155.11	27.45
Rice–fenugreek–okra	68.49	102.94	15.98	468	385.14	59.80
Rice–onion – cowpea	78.08	84.74	14.54	486	296.52	50.19
Rice–chickpea–sesamum	80.82	34.88	6.38	388	105.58	19.34
SEM ±	2.76	1.88	0.39	14.16	5.39	1.15
CD at (0.05)	8.19	5.60	0.72	42.07	16.03	3.41

Note: Mean of the four years of the study. REY, rice equivalent yield, WUE, water-use efficiency.

attributed mainly to the wheat and groundnut crops in the respective sequences because these crops occupied the field for ~125 and 120 days, respectively. LUE was lowest in the rice–wheat system (63.01%), indicating that this sequence has the scope to include one more short-duration crop like green gram, sunhemp (*Crotolaria juncea*), dhaicha (*Sesbania cannabina*, syn. *S. aculeata* or *S. rostrata*) to restore soil fertility. The latter is particularly suitable because it can fix N with nodules on both stems and roots under waterlogged as well as drained conditions (Becker and Ladha 1994).

The rice–fenugreek–okra cropping sequence, although the most productive, could register only 68.49% of LUE because it occupied the field for only 250 days. However, the rice–fenugreek–okra sequence gave the highest production efficiency (102.94 kg ha^{-1} $days^{-1}$), and field water use efficiency (15.98 kg ha^{-1} mm^{-1}), closely followed by the rice–onion–cowpea sequence with corresponding values of 84.74 kg ha^{-1} $days^{-1}$ and 14.54 kg ha^{-1} mm^{-1}. The inclusion of vegetable crops like okra, cowpea, onion and fenugreek in these two sequences was mainly responsible for the higher production and field water use efficiencies. In general, besides having higher price in the market, vegetables provide acceptable production within a shorter time. RP Sharma et al. (2004) also reported that crop intensification through the inclusion of vegetables and leguminous crops increased production and land use efficiencies. The lowest production and field water use efficiencies were obtained with the rice–sorghum–groundnut and rice–wheat cropping systems, respectively. The rice–onion–cowpea system generated 486 man days $ha^{-1}year^{-1}$, which was highest among the cropping systems. Digging of onion in heavy black soil and picking the cowpea pods for vegetables are labor-intensive operations and increased the total number of man days generated by the system. This was followed by the rice–fenugreek–okra sequence, which generated 468 man days ha^{-1} $year^{-1}$.

From the point of view of economic efficiency, the rice–fenugreek–okra sequence gave the highest production efficiency (385.14 Rs ha^{-1} day^{-1}) and water use efficiency (59.80 Rs ha^{-1} mm^{-1}), followed by the rice–onion–cowpea sequence. Similar results were reported by AK Sharma et al. (2007) in rice-based cropping systems.

Soil fertility status

Data on the fertility status (Table 3) showed that this was similar under rice–sorghum–green gram, rice–sorghum–groundnut, rice–wheat–green gram, rice–fenugreek–okra, rice–mustard–green gram and rice–chickpea–cowpea systems; there was a significant increase in available N after completion of the sequence compared to the initial value of available N. This can be attributed to biological N fixation by legume crops. The lowest available N was recorded under the rice–castor cropping sequence. Available P and K decreased significantly from their initial values in all the cropping systems. The decrease in available P from the initial value might be due to P adsorption and precipitation because of use of saline irrigation water (electrical conductivity 2.5 dS m^{-1} at 25°C) in the post-rainy and summer season crop periods when canal water was not available for irrigation. Among the cropping sequences, significantly higher available P was recorded under the rice–sorghum–groundnut sequence, followed by the rice–onion–cowpea sequence. The decrease in available K was expected because no K fertilizer was applied to any of the crops except to the onion crop. Incidentally, highest available K was registered in rice–onion–cowpea sequence, which could be attributed to K fertilization of the onion crop. Data

Table 3. Available N, P, K and organic carbon contents of soil under various rice-based cropping systems. The soil samples were collected after completion of three cycles of the various systems (2005–2006).

	Available nutrients (kg ha^{-1})			
Treatments	N	P	K	Organic carbon (%)
Rice–wheat–fallow	232.21	30.92	156.49	0.66
Rice–wheat–greengram	257.24	35.34	138.52	0.69
Rice–sorghum–greengram	264.76	34.23	143.62	0.72
Rice–castor	220.45	30.41	140.21	0.66
Rice–mustard–greengram	248.36	36.04	144.52	0.71
Rice–sorghum–groundnut	261.42	38.08	150.06	0.74
Rice–chickpea –cowpea	242.62	32.61	155.45	0.67
Rice–fenugreek–okra	251.62	31.55	153.45	0.70
Rice–onion–cowpea	236.42	37.52	161.18	0.67
Rice–chickpea–sesamum	226.45	36.90	158.24	0.66
Initial soil-test values	213.00	41.30	363.23	0.65
SEM ±	2.08	0.87	1.48	0.02
CD at (0.05)	6.20	2.61	4.44	0.07

Table 4. Economic analysis of various rice-based cropping systems.

Cropping system	Gross return (Rs ha^{-1})	Cost of cultivation (Rs ha^{-1})	Net return (Rs ha^{-1})	Return per Re invested (Rs)
Rice–wheat–fallow	55794	35346	20448	1.58
Rice–wheat –greengram	90997	43358	47639	2.09
Rice–sorghum–greengram	86214	41123	45091	2.09
Rice–castor	63843	35362	28481	1.80
Rice–mustard–greengram	89009	40594	48415	2.19
Rice–sorghum–groundnut	88190	45373	42817	1.94
Rice–chickpea –cowpea	84723	40516	44207	2.09
Rice–fenugreek–okra	148688	52402	96286	2.83
Rice–onion –cowpea	163680	79169	84511	2.06
Rice–chickpea–sesamum	69591	38444	31147	1.81
SEM ±			881	0.03
CD (0.05)			2609	0.09

Note: Mean of the four years of the study.

indicate that the rice–castor cropping system was most exhaustive. These results corroborate the findings of Kumar et al. (2008) who reported that inclusion of a legume crop (green gram, berseem) in the system increased the organic C and availability of N, P and K in the soil.

A significant increase in organic carbon was recorded only under the rice–sorghum-groundnut cropping sequence (Table 4). RP Sharma et al. (2004) also observed that sequences including fodder and legume crops improved the soil fertility. According to Boone (1994), 16–33% of the total C assimilated by plants is released directly into soil by roots, which contributes to 30–60% of the organic C pool in soil. The lowest organic carbon content was found in rice-castor and rice–wheat cropping sequences.

Economics

Among the various systems, rice–fenugreek–okra realized the highest net returns (96,286 Rs ha^{-1}), followed by rice–onion–cowpea (84,511 Rs ha^{-1}) (Table 4). Inclusions of vegetable crops like fenugreek, okra, onion and cowpea in the cropping systems in addition to increasing system productivity, also fetched higher market prices, thereby increasing the net returns. Kumar et al. (2008) also reported that the inclusion of vegetable crops in rice-based crop sequences improved net returns. Growing vegetable crops during the summer in areas with assured irrigation is economically remunerative because the supply of vegetables from rainfed areas is drastically reduced during summer. However, other cropping systems gave similar but significantly higher net returns than the rice–wheat system. Returns per rupee invested was highest for rice–fenugreek–okra (2.83 Rs), followed by rice–mustard–green gram (2.19 Rs).

Conclusions

Under the soil and agroclimatic conditions of south Gujarat, India, rice–fenugreek–okra, followed by rice–onion–cowpea, was more productive, sustainable, resource-use efficient and remunerative than other cropping systems. However, farmers practicing cattle and crop mixed farming could follow rice–sorghum–groundnut or rice–sorghum–green gram cropping sequence and ensure green fodder for cattle during the post-rainy season besides providing nutritious diet to the family and maintaining soil fertility through the inclusion of legumes.

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