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

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Continuous adoption of rice-rice cropping system has led to deterioration of soil quality resulting in a serious threat to its sustainability in high rainfall zone of South Gujarat, India. Therefore crop diversification with wider choice in the production of a variety of crops is being promoted to restore the soil quality. A field experiment was conducted at Navsari, India during 2003-2007 on heavy black soil to evaluate the production potential, sustainability, resource-use efficiency and economics of 10 cropping systems based on rice (Oryza sativa L.). System productivity of rice - fenugreek -okra was the highest (25.73 ton/ha) followed by rice-onion-cowpea (24.15 ton/ha). Lowest System productivity was registered with rice-wheat-fallow system (7.85 ton/ha). Sustainable yield index (0.94), production efficiency (102.94 kg/ha/day), and field water use efficiency (32.99 kg/ha-cm) were maximum with rice - fenugreek -okra system. Similarly, net return (Rs 96286/ha), net return per rupee invested (Rs 2.84), and production efficiency (Rs 385.14 /ha/day) and field water use efficiency (Rs 1234.43/ha-cm) in economic terms was maximum with rice - fenugreek -okra cropping sequence. Thus rice - fenugreek -okra was the most productive, sustainable, resource-use efficient and remunerative cropping system followed by rice-onion-cowpea system.

Key words: crop diversification, resource use efficiency, rice-equivalent yield, sustainability.

Introduction

Rice - rice- fallow is the most dominant crop sequence in the heavy black soil region of South Gujarat, India. Continuous cultivation of rice for longer periods with low system productivity, and often with poor crop management practices, results in loss of soil fertility due to emergence of multiple nutrient deficiency (Fujisaka et al., 1994; Singh and Singh, 1995; Dwivedi et al., 2001) and deterioration of soil physical properties (Tripathi, 1992), and decline in factor productivity and crop yields in high productivity areas (Yadav, 1998). During cultivation of rice soil undergoes drastic changes, i.e. aerobic to anaerobic environment, leading to several physical and electro-chemical transformations. Puddling breaks capillary pores, reduces void ratio, destroys soil aggregates, disperses fine clay particles, and lowers soil strength in the puddled layer (Sharma and De Datta, 1986). In systems that are frequently wet and dry, there is potential for significant loss of N by leaching and denitrification. Further, since nitrite is an intermediate in both the reduction of nitrate and the oxidation of ammonia, aerobic denitrification via nitrate may be more substantial and widespread than previously realized, especially on soils that are alternately wet and dry (Ponnamperuma, 1972).

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Cassman *et al.* (1995) and Olk and Cassman (1995) proposed that the now commonly observed, smaller than previous response to N fertilizer in continuously flooded rice systems, is associated with sequestration of N in resistant lignin compounds formed from the large amounts of retained crop residues. If this is the case, then perhaps there is an important role for rice rotations that include upland crops, such as wheat and grain legumes, to break this sequestration of N. Diversification and intensification of rice-based system to increase productivity per unit resource is very pertinent. Crop diversification shows lot of promises in alleviating these problems besides, fulfilling basic needs for cereals, pulses, oilseeds and vegetables and, regulating farm income, withstanding weather aberrations, controlling price fluctuctuation, ensuring balanced food supply, conserving natural resources, reducing the chemical fertilizer and pesticide loads, ensuring environmental safety and creating employment opportunity (Gill and Ahlawat, 2006). Crop diversification has been recognized as an effective strategy for achieving the objectives of food security, nutrition security, income growth, poverty alleviation, employment generation, judicious use of land and water resources, sustainable agricultural development and environmental improvement (Hedge et al., 2003). The crop diversification may enhance profitability, reduce pests, spread out labour more uniformly, reduce risks from aberrant weather by different planting and harvesting times and source of high value products from new crops (Reddy and Suresh, 2009). In the era of shrinking resource base of land, water and energy, resource use efficiency is an important aspect for considering the suitability of a cropping system (Yadav, 2002). Hence, selection of component crops needs to be suitably planned to harvest the synergism among them towards efficient utilization of resource base and to increase overall productivity (Anderson, 2005). Because of high rainfall (average annual rainfall 1650 mm) during rainy season (June -September), frequent flooding with runoff water from uplands, heavy black soil having low workability when wet and weed menace and beside, rice being the staple food of people here rice can not be replaced with other crops during rainy season. Hence the only option left is to identify suitable crops for post rainy (November to February) and summer (March to May) seasons. Growing of crops such as vegetables, pulses and oilseeds in place of post rainy season rice is an alternative approach for realizing higher productivity and profitability (Newaj and yadav, 1992). Moreover, growing non paddy crops during post rainy season has a special reference for efficient utilization of irrigation water, labour and other inputs for higher productivity, profitability and food security (Satyasai and Viswanathan, 1996).There is need to evaluate the possibilities of replacing post rainy season rice with other suitable upland crops and include summer season crops for higher productivity, resource use efficiency and sustainability. Similarly, there are opportunities to include grain legumes and vegetables during summer season however, the growing period available after post rainy season crops and before rice is short (50-70 days), early rains during the summer season promote disease, and late rains can damage or destroy the harvest. Though a range of warm and cool season legumes can be grown, the choice of species for rice-based systems is limited. Suitable grain legumes must either complete their life cycle before the start of monsoons, or tolerate transient waterlogging in the latter part of their growth period. High yielding, short-duration, disease-resistant grain legumes have the best chance of acceptance by farmers for their ability to fit into existing rice-based system and maintain or improve the short- and long-term productivity and economic viability of the system. Grain legumes will only be accepted by farmers if they can be established with small amounts of water soon after harvest of post rainy season crops particularly, when supply of canal water during summer is increasingly becoming limited and, can mature before the monsoon starts. Cowpea (*Vigna sinensis* L.), groundnut (*Arachis hypogea*), and mungbean (*Vigna radiata*) are potential grain legumes for this region. But legume crops' demand for macronutrients (P, Ca, Mg, and S) that they require in larger quantities than cereals, and the micronutrients (Co, Mo) needed for effective rhizobial symbiosis must be fulfilled through applying recommended dose of nutrients. Constraints like high water requirement during summer season, and delay in rice planting due to long duration of summer grain legumes, however, restrict the integration of legumes in cereal–cereal systems on a large-scale (Ali, 1999). Nonetheless, development of short-duration and uniformly maturing varieties of summer legumes (cowpea and green gram) may enhance the feasibility of inclusion of grain legumes in rice-based system. With increasing purchasing power of people in the country, the demand for vegetable crops has increased enormously leading to sharp increase in their prices and it has been the dominant factor for high inflationary pressure in Indian economy during recent years. Inclusion of crops like oilseeds, pulses, vegetables and fodder crops will improve the economic condition of small and marginal farmers owing to higher price and/or higher volume of their main and by-products (Sharma *et al*., 2007). Hence, efforts are being made to promote diversification of rice- based cropping sequence in this zone of country with legumes and vegetable crops for sustaining the productivity and meet out demand for vegetables, pulses and oilseeds. Therefore, the present investigation was carried out to find out most productive, resource-use-efficient and remunerative cropping system for this region.

Materials and methods

A field experiment was conducted at All India Coordinated Research Project (AICRP) on Cropping System Research Farm, Navsari Agricultural University, Navsari, India during 2003-2007 on the same site and lay out. The experimental soil was clayey in texture (66.25 % clay), alkaline in reaction (pH 7.8), low in available N (213.0 kg/ha) and medium in available P and K (41.3 and 163.0 kg/ha, respectively). The region predominantly enjoys maritime climate; being situated 15 km East of Arabian Sea coast. Climate is humid and diurnal and seasonal variations in temperature remain in a narrow range (minimum temperature of coldest month is 12.4 ^{o}C while maximum temperature of warmest month is 40.0 ^{o}C) .Ten different cropping sequences were tried in randomized block design (RBD) with three replications. These were, T_1: rice-wheat (*Triticum aestivum*) -fallow,T_2:rice-wheat-greengram (*Vigna radiata*),T_3 :rice- sorghum

(*Sorghum bicolor*)-greengram,T_4:rice-castor (*Ricinus communis*),T_5:rice-mustard (*Brassica juncea*)-greengram,T_6:rice-sorghum- groundnut (*Arachis hypogea*),T_7:rice-chickpea (*Cicer arietinum*)-cowpea (*Vigna sinensis* L.), T_8:rice-fenugreek (*Trigonella foenum-graecum*)-okra (*Abelmoschus esculentus*), T_9:rice-onion (*Allium cepa*) -cowpea and T_{10} : rice-chickpea-sesamum (*Sesamum indicum*). In case of T_4 summer crop could not be grown due to long duration of castor crop. The varieties of different crops used were: rice 'GR-3', wheat 'GW-496', greengram '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 x 6.0 m.

In the rainy season 25 days old rice seedlings were transplanted manually in field during first week of July depending on onset of monsoon, and crop was harvested in the third week of October. The subsequent post rainy season crops were sown by hand during second fortnight of November except, onion in which 25 days old seedlings were transplanted during second fortnight of December. Summer season crops were sown manually after harvest of preceding post rainy season crops at recommended time of sowing for different summer season crops in the region. Seeds of legume crops were treated with crop specific *Rhizobium* and phospho-bacteria before sowing. In rice to reduce the water losses through deep percolation and seepage, impervious soil layer was created in sub-surface by puddling which included 4-5 cross cultivations in 5 cm standing water in field by power tiller followed by leveling and bunding. Just after harvest of rice the plots were irrigated and prepared for sowing of ensuing post rainy season crops using two cross cultivations and two harrowings followed by planking. For summer season crops field preparation included one deep ploughing using mould board plough followed by 2 harrowings and planking. Seed rate and spacing maintained for different crops was; rice (20 x 15 cm and 25 kg/ha), wheat (22.5cm and 120 kg/ha), fodder sorghum (30 x 8 cm and 30 kg/ha), castor (90 x 60 cm and 6.0 kg/ha), mustard (45 x 15 and 4.0 kg/ha), chickpea (30 x 10 cm and 60.0 kg/ha), fenugreek (broadcasting and 40.0 kg/ha), onion (15 x 10 cm and 10.0 kg/ha), greengram (30 x 10 cm and 25.0 kg/ha), groundnut (30 x 10 cm and 120.0 kg/ha), cowpea (30 x 10 cm and 30.0 kg/ha), okra (30 x 10 cm and 10.0 kg/ha), and sesamum (45 x 10 cm and 2.5 kg/ha), respectively. Crops were fertilized with recommended dose of NPK (kg/ha): rice (100-50-00), wheat (120-60-00), sorghum (80-40-00), castor (75-50-00), mustard (50-50-00), chickpea (20-40-00), fenugreek (25-00-00), onion (75-50-50), greengram (20-40-00), groundnut (25-50-00), cowpea (20-40-00), okra (150-50-00), and sesamum (25-50-00). Whole of P and K and basal dose of N was drilled in rows 5-6 cm below seeds before sowing/planting of crops whereas remaining dose of N was applied in split doses as per scientific recommendations for region in different crops. In rice whole of P and K and basal dose of N was given before puddling and incorporated in soil. Urea (46.4% N) was used as source of N, single super phosphate, SSP (16.99% P) for P and muriate of potash, MOP (49.6 %K) for K. In rice, entire water requirement of crop was met through rainfall. Post rainy *and* summer season crops were grown entirely either with canal water or tubewell water as rainfall remains negligible during this period in this part of India. At each irrigation 5 cm water was applied which was measured using parshall flume. Recommended interculturing practices and plant protection measures were followed as and when required for successful cultivation of crops. In post rainy season, sorghum was harvested for fodder purpose, fenugreek for vegetable as green leaves, onion as bulbs and rest of the crops for grains. In 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 30 days after sowing just above ground level using sickles. For easiness in digging in groundnut and onion irrigation was given 5-6 days earlier to harvest. Economic yields of the component crops were converted to rice- equivalent yield (REY), taking into account the prevailing market price (Rs./kg) 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), greengram (25.0), groundnut (15.0), cowpea (10.0), okra (10.0), and sesamum (30.0). Selling price of residual crop biomass sold as cattle fodder was (Rs. /kg): rice and wheat (1.20), greengram (1.40), chickpea (1.25), groundnut (1.25) and cowpea (0.70). Whereas remaining crop biomass of castor, okra, and onion was removed from the plots after harvest of economic parts. Total field duration of a cropping system expressed in percentage of 365 days was taken as the land use efficiency, LUE (Tomar and Tiwari, 1990) of the system. Production efficiency was expressed as the ratio of system productivity in kg REY/ha to total duration of the system in days (Patil *et al*., 1995). Water use efficiency (WUE) was computed by dividing system productivity with water requirement of the system and was expressed as kg REY/ha-cm of water uses. Production efficiency and water use efficiency in economic term were calculated by taking net return instead of REY. Sustainable yield index (SYI) was calculated as per Guggari and Kalaghatagi, 2004.

$$\text{Sustainable yield index} \quad \frac{\bar{Y} - б}{Y\ Max}$$

Where,

$\bar{Y}$ = estimated mean yield
б = estimated standard deviation
Y Max = observed maximum yield in the experiment over the years

Economic analysis

For economic evaluation of different rice-based cropping sequences averaged data of four crop cycles were used. The gross cost of cultivation of different crops grown was calculated on the basis of different 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): rice seed (13.20), wheat seed (15.00), greengram seed (40.0), sorghum seed (30.0), castor seed (100.0), mustard seed (40.0), chickpea seed (20.0), cowpea seed (20.0), fenugreek seed (25.0), groundnut seed (26.15), onion seed (150.0), okra seed (140.0) and sesamum seed (50.0) and, Rs. 5.20 /kg of urea, Rs. 3.30 /kg of SSP, Rs. 4.66 /kg of MOP and Rs. 260 /litre of butachlor. Among field operations, the cost of plowing/harrowing was taken as Rs. 110, labour Rs. 50, irrigation Rs. 120 and puddling Rs.500. Gross returns included income from sale of main product of all crops and straw/haulm in rice, wheat, greengram, groundnut, chickpea and cowpea. Net returns were the difference between the gross return of a system and total cost of cultivation of the component crops in this system. For treatment comparisons 'F-test' was used, following the procedures of randomized block design (Cochran and Cox, 1957).

Results and discussion

Productivity of component crops

It was found that yield of component crops varied fairly according to cropping systems. Rice yield was found highest (5.12 ton/ha) under rice-onion-cowpea sequence compared to other sequences (Table 1). It was found that cropping sequences including legumes performed fairly well with regard to rice productivity. Reports from different parts of the country indicated that inclusion of legumes in rice-based system increased the productivity of rice (Hegde, 1992). Introduction of a legume crop in rice-based cropping system may have advantages well beyond the N addition through biological nitrogen fixation including nutrient recycling from deeper soil layers, minimizing soil compaction, increase in soil organic matter, breaking of weed and pest cycles and minimizing harmful allelopathic effects (Sanford and Hairston, 1984; Wani *et al*., 1995). Minimum rice yield was recorded under rice -castor sequence (4.73 ton/ha). It might be due to nutrient exhaustive nature of castor crop (75-50-00 kg/ha of NPK) which adversely affects the growth and development of succeeding rice in the rotation. Further, it was also found that rice yield was lower when sorghum (fodder) was included in the sequence. Similar results were also reported by Kumar *et al*., (2008) and Bastia *et al*., (2008) in rice-based cropping systems.

Among post rainy season crops, wheat yield was equal under both rice-wheat-greengram and rice-wheat-fallow systems. Even than yield level of wheat was much lower as compared to average wheat productivity (4.0 ton/ha) in irrigated belt of Indo-Gangatic Plains (IGP) in North India. It can be mainly attributed to lack of suitable thermal requirements to wheat. As against mean daily temperature requirement of wheat at germination, tillering, accelerated growth and grain filling stages of 20 to 25, 16 to 20, 20 to 23 and 23 to 25 ^{0}C, the mean daily temperature at experimental site during these stages was 27, 23.5, 25, and 27 ^{0}C respectively (mean data of four years of study). Due to high temperature plants have poor tillering, stunted growth, reduced foliage area which, in turn leads to reduction in total number of spikes and spikelets as well as supply of photosynthates for grain filling and development. High temperature also forces the plants to enter into reproductive phase earlier and plants complete life cycle about 25 days earlier as compared to that in North India. This ultimately culminates in lower yield of wheat in this part of country. Subsurface compaction caused by puddling reduces root growth of wheat (Oussible *et al*., 1992; Aggarwal *et al*., 1995) which in turn also reduces wheat productivity. Yield of sorghum was higher under rice-sorghum-greengram sequence than in rice-sorghum-groundnut sequence. Productivity of castor, fenugreek and onion (2.11, 8.04, and 25.52 ton/ha, respectively) following rice was higher as compared to average productivity of these crops in the region (1.92, 5.50, and 24.23 ton/ha, respectively). Productivity of mustard and chickpea was low as compared to national productivity (1.01 t/ha and 0.76 t/ha, respectively) of these crops (Anon., 2009). Lower yield of mustard can be attributed to high temperature during vegetative phase leading to low plant height, poor branching, lower leaf area which resulted into poor crop yield. Chickpea requires clodded soil for better aeration but due to clayey soil and disturbed soil structure due to puddling for rice proper seed bed preparation for chickpea could not be accomplished. Impaired soil structure, poor aeration, excess moister retention for extended period in the plough-soil layer due to puddling and continuous submergence of rice might have resulted in low crop stand, restricted root growth, poor nodulation (chickpea) and hence growth and yield of post rainy season crops like mustard and chickpea (Prasadini et al.1993). Puddling also affects survival of beneficial organisms, the most important of which are the microorganisms responsible for the fixation of atmospheric N and its transformations in the soil. Among the summer crops yield of greengram was higher under rice-sorghum-greengram sequence (1.15 ton/ha) compared to rice-wheat-greengram (1.11 ton/ha) and rice-mustard-greengram (1.09 ton/ha) sequence. Lower yield of greengram under rice-mustard-greengram and rice-wheat-greengram sequences might be due to higher nutrient uptake by grains and straw of mustard and wheat compared to fodder sorghum. Cowpea yield was higher in rice-chickpea-cowpea sequence than in rice-onion-cowpea sequence. Nutrient recycling from deeper layers by chickpea could benefit succeeding cowpea as against shallow rooted and nutrient exhaustive onion (75-50-50 kg NPK/ha). Yield level of groundnut (2.15 ton/ha) was lower than the productivity of improved groundnut varieties in field demonstrations (3.0 to 3.2 ton/ha). Lower yield of groundnut could be attributed to difficulties in peg penetration due to hard soil surface of heavy black soil, poor pod setting and development. Okra and sesamum as summer crops performed well. This type of variation in the yield of crops might be attributed to the biological and environmental complexities and interactions in the cropping systems (Francis, 1989).

System Productivity

Pooled data indicated that system productivity in terms of rice-equivalent yield (REY) was maximum in case of rice-fenugreek-okra (25.73 ton/ha) sequence (Table 1). It can be attributed mainly to okra which fetched higher prices in the market besides having good productivity (6.91 ton/ha). The next in the order was rice- onion - cowpea cropping sequence. Here, onion contributed most (68.58%) to enhance the equivalent yield due to its higher marketable yield (25.52 ton/ha). Barring the onion, it was the summer season crops which governed the REY of the systems, because rice being the base crop and contribution of post rainy season crops was not optimal. These results corroborates the findings of Singh et al (2007) who reported rice-pea-okra followed by rice-pea-onion as the most productive cropping sequence for eastern Uttar Pradesh, India. Mishra *et al* (2007) also reported higher productivity and profitability through inclusion of vegetables and pulses in rice-based cropping system. The contribution of summer crops to REY of rice-wheat-greengram, rice-sorghum-greengram, rice-mustard-greengram, rice- sorghum-groundnut, rice-chickpea-cowpea, rice-fenugreek-okra, rice-chickpea-sesamum was 37%, 39%, 36%, 43%, 41%, 49% and 36% respectively. Lowest REY (7.85 ton/ha) was recorded under rice-wheat-fallow system. It clearly shows the importance of summer crops to raise the system productivity and sustainability. Among the cropping sequences involving summer crop, lowest REY was recorded with rice-sorghum-greengram and rice-sorghum-groundnut cropping sequences. Fodder sorghum known for its allelopathic effect on the following crops, might have adversely affected the productivity of succeeding crops in the rotation (Ben-Hammounda et al., 1995, Cheema, 1998 and Kim et al., 1993).

Sustainable yield index (SYI)

Rice-fenugreek-okra recorded the highest SYI of 0.97 followed by rice-onion-cowpea sequence (0.91). It indicates that the minimum guaranteed yield obtained from these sequences is 97% and 91% respectively and are less affected by seasonal variations. Further, it can be seen that cropping sequences involving legumes recorded higher SYI compared to non- legumes. Legumes are known to offer special advantage regarding stability of the system because of their legumes effect 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 requirements through biological N fixation (BNF), `sparing' soil N compared with non-legume alternatives, and benefiting subsequent crops (Timsina and Connor, 2001).

Resource-use efficiency

Rice-wheat-greengram and rice- sorghum-groundnut cropping sequences registered highest land use efficiency (83.56% in both) (Table 2). It can be attributed mainly to wheat and groundnut crops in respective sequences because these crops occupied the field for about 125 and 120 days respectively. The land use efficiency (LUE) was lowest in rice - wheat - fallow system (63.01%) indicating that it has the scope to include one more short duration crop like greengram, sunhemp (*Crotolaria juncea*) or dhaicha (*Sesbania cannabina,* syn. *S. aculeata*) and *S. rostrata* for soil fertility restoration. The latter is especially suitable because, with nodules on both stems and roots, it can fix N under flooded as well as drained conditions (Becker and Ladha, 1994).

Rice - fenugreek -okra cropping sequence though being the most productive sequence could register only 68.49% of land use efficiency because it occupied the field for 250 days only. Rice - fenugreek -okra sequence registered the highest production efficiency (102.94 kg/ha/days), and field water use efficiency (32.99 kg/ha-cm). It was closely followed by rice-onion-cowpea sequence, with corresponding values of 84.74 kg/ha/days and 23.00 kg/ha-cm. Inclusion of vegetable crops like okra, cowpea, onion and fenugreek in these two sequences was mainly responsible for higher production efficiency and field water use efficiency. Vegetables besides having higher price in the market give good production in lesser period of time. Sharma *et al.* (2004) have also reported that intensification through inclusion of vegetables and leguminous crops increase the production and land use efficiency. Lowest production efficiency and field water use efficiency was found with rice-sorghum-groundnut and rice-chickpea-sesamum cropping sequences, respectively. Rice-onion-cowpea generated highest number of man days/ha/year (486). Digging of onion in heavy black soil and picking the cowpea pods for vegetable purpose are the labour intensive operations thereby increasing the total number of man days generated in this system. It was followed by rice-fenugreek-okra with 468 man days generated/ha/year. From economic efficiency point of view, rice - fenugreek - okra expressed highest production efficiency (Rs 385.14/ha/day) and water use efficiency (Rs 1234.43/ha-cm) followed by rice-onion-cowpea (Rs 296.52/ha/day and 804.86/ha-cm respectively). Similar results have also been reported by Sharma *et al*., (2007).

Economics

Among the systems, rice - fenugreek -okra realized the highest net returns (Rs 96286/ha) followed by rice-onion-cowpea (Rs 84511 /ha) (Table 3). Inclusion of vegetable crops like fenugreek, okra, onion and cowpea in these cropping systems besides, increasing the system productivity, fetched higher market price thereby, increasing the net returns. Kumar *et al.* (2008) also reported that inclusion of vegetable crops in rice- based crop sequences improved the net returns. Growing vegetable crops during summer in areas with assured irrigation facilities is economically remunerative as supply of vegetables from rainfed areas is drastically reduced during summer and vegetable prices soar up. Therefore, excess of vegetables produced can be transported in areas of high demand. However, rice-wheat-greengram and rice- sorghum-greengram, rice-wheat-greengram and rice-mustard-greengram, rice- sorghum-greengram and rice-chickpea -cowpea; and rice-sorghum-groundnut and rice-chickpea -cowpea remained at par in terms of net returns. Lowest net return (Rs 20448/ha) was obtained with rice-wheat -fallow cropping system. Returns per rupee invested was highest for Rice - fenugreek -okra (Rs 2.84) followed by rice-mustard-greengram (Rs 2.19). This was due to high gross returns of these systems.

Conclusion

Based on findings of this experiment it can be concluded that under conditions of South Gujarat, India rice-fenugreek-okra followed by rice-onion-cowpea cropping system was more productive, sustainable, resource-use efficient, and remunerative. If there is fall in market price of crops like fenugreek and okra, farmers can shift to crops like onion and cowpea. Onion has high demand both within country as well as outside and can be stored for sufficient long period (4-5 months) by farmers using indigenous techniques if demand in market is low. Similarly in case of cowpea, if demand for green pods decreases farmers can harvest crop for grain purpose to avoid marketing losses. It can also be concluded that farmers of command-tail area can follow rice-castor cropping system if sufficient water for irrigation is not available during summer months. Farmers practicing mixed farming of cattle with crops can follow rice-sorghum-groundnut cropping sequence ensuring green fodder for cattle during post rainy season.

References

Aggarwal GC, Sidhu AS, Sekhon NK, Sandhu KS, Sur HS. 1995. Puddling and N management effects on crop response in a rice±wheat cropping systems. Soil Till. Res. 36, 129±139. Ali, M., 1999. Evaluation of green manure technology in tropical lowland rice systems. Field Crops Res. 61, 61–78.

Anonymous. 2009. Agricultural statistics at a glance. Published by Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Govt. of India.

Becker M, Ladha JK. 1994. Green manure technology: potential, usage, limitations. In: Proceedings of the 15th World Congress of Soil Science. International Society of Soil Science and Mexican Society of Soil Science, Sociedad Mexicana de la Ciencia del Suelo, Chapingo, Mexico, pp. 267-272.

Ben-Hammounda M, JK Robert and CM Harry. 1995. Phytotoxicity of extracts from sorghum plant components on wheat seedlings. Crop Sci.. 35(6): 1652-1656.

Anderson, RI. 2005. Are some crops synergistic to following crops? Agronomy Journal 97(1): 7-10.

Bastia DK, Garnayak LM and Barik T. 2008. Diversification of rice (Oryza sativa) - based cropping systems for higher productivity, resource-use efficiency and economics. Indian Journal of agronomy 53(1): 22-26.

Cassman KG, Olk DC, Brouder SM, Roberts BA. 1995. The infuence of moisture regime, organic matter and root ecophysiology on the availability and acquisition of potassium: implications for tropical lowland rice. In: Potassium in Asia. Proceedings of the 24th International Colloquium of the International Potash Institute. International Potash Institute, Basel, pp. 135-156.

Cheema ZA. 1998. Sorghum allelopathy – aew weed control technology for enhancing wheat productivity. JAPS, 8(1-2): 19-21.

Cochran,W.G., Cox, G.M., 1957. Experimental Designs.Wiley, NY, USA.

Dwivedi BS, Shukla AK, Singh VK, Yadav, RL. 2001. Results of participatory diagnosis of constraints and opportunities (PDCO) based trials from the state of Uttar Pradesh. In: Subba Rao, A., Srivastava, S. (Eds.), Development of Farmers' Resource-Based Integrated Plant Nutrient Supply Systems: Experience of a FAO–ICAR–IFFCO Collaborative Project and AICRP on Soil Test Crop Response Correlation. IISS, Bhopal, India, pp. 50–75.

Francis CA. 1989. Biological efficiencies in multiple cropping systems. Advances in Agronomy 42:1-36.

Fujisaka S, Harrington L, Hobbs P. 1994. Rice–wheat in South Asia: systems and long-term priorities established through diagnostic research. Agric. Syst. 46, 169–187.

Gill MS and Ahlawat IPS. 2006. Crop diversification - its role towards sustainability and profitability. Indian Journal of Fertilizers 2 (9): 125-138, 150.

Guggari AK and Kalanghatagi SB. (2004). Effect of in situ moisture conservation techniques on pearl millet in medium black soil under dry land conditions. J. Farming System Research and Development , 10 (1&2) : 22-28.

Hegde DM. 1992. Cropping System Research- Highlights. Project Directorate for Cropping System Research, Modipuram, Meerut, Utter Pradesh. pp. 40.

Hegde DM, Prakash Tiwari S and Rai M. 2003. Crop diversification in Indian Agriculture. Agricultural Situation in India. August, 2003. pp. 351-354.

Kim SY, SK De Dutta RP Robels KU Kim SC Lee and DH Shin. 1993. Allelopathic effects of sorghum extract and residues on selected crops and weeds. Korean J. Weed Sci., 14 (1) 34-41.

Kumar Alok, Tripathi HP, Yadav RA and Yadav, SR 2008. Diversification of rice (Oryza sativa) - wheat (Triticum aestivum) cropping system for sustainable production in eastern Uttar Pradesh. Indian Journal of agronomy 53(1): 18-21.

Mishra MM, Nanda SS, Mohanty M, Pradhan KC and Mishra SS. 2007.Crop diversification under rice based cropping system in western Orissa. In: Extended summaries 3rd National Symposium on Integrated Farming Systems, October 26-28, 2007 organized by Farming System and Development Association (Project Directorate for Cropping System Research, Modipuram, Meerut) at Agricultural Research Station, Durgapura, Jaipur.

Newaj R and Yadav DS. 1992. Production potential and labour employment under different cropping systems under upland conditions of eastern UP. Indian Journal of GAronomy 37 (3): 401-406.

Olk DC, Cassman KG. 1995. Characterization of two chemically extracted humic acid fractions in relation to nutrient availability. ACIAR Proceedings No. 56. ACIAR, Canberra, Australia, pp. 131-134.

Oussible M, Crookstan RK, Larson WE. 1992. Subsurface compaction reduces the root and shoot growth and grain yield of wheat. Agron. J. 84, 34±38.

Patil EN, Jowale S and Mahayan MS. 1995. Production potential, economics and fertility status of soil as influenced by wheat - based cropping system. Indian Journal of agronomy 40(40): 544-548.

Ponnamperuma FN. 1972. The chemistry of submerged soils. Adv. Agron. 24, 29-96.

Prasadini PP, Rao MS and Rao SR. 1993. effect of tillage on clod size distribution, penetration resistance and yield of groundnut in rice-based cropping system after puddle rice. Journal of Oildeeds Research. 10:62-65

Reddy BN and Suresh G. 2009. Crop diversification with oilseed crops for-maximizing productivity, profitability and resource conservation. Indian Journal of Agronomy 54(2): 206-214.

Satyasai KJS and Viswanathan KU. 1996. Diversification of Indian Agriculture and Food Security. Indian Journal of Agricultural Economics. 51(4): 674-679.

Sharma AK, Thakur NP, Koushal Sanjay, Kachroo Dileep. 2007. Profitable and energy efficient rice-based cropping system under subtropical irrigated conditions of Jammu. In: Extended summaries 3rd National Symposium on Integrated Farming Systems, October 26-28, 2007 organized by Farming System and Development Association (Project Directorate for Cropping System Research, Modipuram, Meerut) at Agricultural Research Station, Durgapura, Jaipur.

Sharma PK, De Datta SK. 1986. Physical properties and processes of puddled rice soils. Adv. Soil Sci. 5, 139-178.

Sharma RP, Pathak SK, Haque M and Raman KR. 2004. Diversification of traditional rice (Oryza sativa) - based cropping systems for sustainable production in south Bihar alluvial plains. Indian Journal of Agronomy 49(4): 218-222.

Singh J, Singh JP. 1995. Land degradation and economic sustainability. Ecol. Econ. 15, 77–86.

Singh P, Singh JP, Gill MS and Singh Y. 2007. Alternate cropping systems to sugarcane-ratoon-wheat in peri urban areas of Meerut. In: Extended summaries 3rd National Symposium on Integrated Farming Systems, October 26-28, 2007, organized by Farming System and Development Association (Project Directorate for Cropping System Research, Modipuram, Meerut) at Agricultural Research Station, Durgapura, Jaipur.

Sanford JO, Hairston JE. 1984. Effects of N fertilization on yield, growth and extraction of water by wheat following soybean and sorghum. Agron. J. 76, 623–627.

Timsina J and Connor DJ. 2001. Productivity and management of rice-wheat cropping systems: issues and challenges. Field Crops Research 69 (2001) 93-132.

Tripathi RP. 1992. Physical properties and tillage of rice soils in rice–wheat system. In: Pandey, R.K., Dwivedi, B.S., Sharma, A.K. (Eds.), Rice–wheat Cropping System. PDCSR, Modipuram, India, pp. 53–67.

Tomar SS and Tiwari AS. 1990. Production potential and economics of different cropping sequences. Indian Journal of Agronomy 35(1, 2): 30-35.

Wani SP, Rupela OP, Lee KK. 1995. Sustainable agriculture in the semi-arid tropics through biological nitrogen fixation in grain legumes. Plant Soil 174, 29–49.

Yadav JSP. 2002. Agricultural resource management in India: the challenges. Journal of Agricultural Water Management 1(1):61-69.

Yadav RL. 1998. Factor productivity trends in a rice–wheat cropping system under long-term use of chemical fertilizers. Exp. Agric. 34, 1–18.

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

Cropping system	Economic yield (ton/ha)			Straw/haulm/stover yield (ton/ha)			System productivity (REY ton /ha)	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	4.73	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	
CD at (0.05)							1.29	

‘(Mean of four years)’ * green fodder yield, **green pod yield, ***green leaves yield.

Table2. Resource use efficiency and mandays/ha generated under different rice-based cropping systems

Cropping system	Land- use efficiency (%)	Production efficiency Kg REY /ha/ day	Total quantity of water supplied (cm)	WUE (kg REY/ha-cm)	Man-days /ha/year	Economic efficiency	
						Production efficiency Rs /ha/ day	WUE (Rs/ha-cm)
Rice-wheat-fallow	63.01	34.17	72	10.92	321	88.90	284.00
Rice-wheat -greengram	83.56	40.83	96	12.97	397	156.19	496.23
Rice-sorghum-greengram	71.23	36.30	66	14.30	386	173.42	683.19
Rice-castor	72.60	36.68	64	15.19	338	107.47	445.00
Rice-mustard-greengram	76.71	45.69	84	15.23	399	172.91	576.36
Rice-sorghum-groundnut	83.56	33.48	78	13.09	414	140.38	548.93
Rice-chickpea -cowpea	78.08	39.24	76	14.72	403	155.11	581.67
Rice-fenugreek-okra	68.49	102.94	78	32.99	468	385.14	1234.43
Rice-onion -cowpea	78.08	84.74	105	23.00	486	296.52	804.86
Rice-chickpea-sesamum	80.82	34.88	96	10.72	388	105.58	324.44

‘(Mean of four years)’

Table 3. Economics of different rice-based cropping systems

Cropping system	Gross return (Rs/ ha)	Cost of cultivation(Rs/ ha)	Net return (Rs/ ha)	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±			00881	0.03
CD at 5%			02609	0.09

‘(Mean of four years)’