Indian Journal of Agricultural Sciences **80** (10): 858–63, October 2010

Determination of time frame for substitution of salt-tolerant varieties of rice (*Oryza sativa*) and wheat (*Triticum aestivum*) through crop diversification in sodic soils

Y P SINGH[1], RANBIR SINGH[2] and D K SHARMA[3]

Regional Research Station, Central Soil Salinity Research Institute, Lucknow, Uttar Pradesh 226 005

Received: 9 July 2009; Revised accepted: 19 July 2010

ABSTRACT

A field experiment was conducted during 2001–05 at Regional Research Station, Central Soil Salinity Research Institute, Lucknow to determine the time frame for substitution of salt-tolerant varieties of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L. emend. Fiori & Paol.) through crop diversification. Under resource-scarce conditions, application of gypsum @ 25% gypsum requirement and growing salt-tolerant varieties of rice 'CSR 13' for 4 years and wheat 'KRL 19' for 3 years was found optimum time for substitution of salt-tolerant varieties through crop diversification. However, under resource-rich conditions where gypsum is available to fulfill 50% gypsum requirement, crop diversification under sodic soils may be initiated after growing of salt-tolerant varieties of rice for 3 years and of wheat for 2 years. After 4 years of rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L. emend. Fiori & Paol.) cropping system, the pH_2 of surface soil with 25 and 50% gypsum requirement levels reduced to 9.12 and 8.87, respectively or say the soil is partially reclaimed. There are certain highly remunerative crops, like sweet basil (*Ocimum basilicum* L.), matricaria (*Matricaria chamomilla* L.), chilli (*Capsicum* spp) and garlic (*Allium sativum* L.) which may grow at this sodicity level and gave high economic returns. On the basis of crop diversification study, rice equivalent yield (14.21 tonnes/ha) and production efficiency (61.25 kg/ha/day) was higher with sweet basil–matricaria cropping system over the traditional rice–wheat system. Chilli–garlic cropping system recorded the highest water-expense efficiency (150.72 kg/ha cm), followed by sweet basil–matricaria but the total amount of water used was more (125.65 cm) in rice–wheat system. The water requirements of sweet basil–matricaria and chilli–garlic cropping systems were 19.8 and 31.8% less than that of rice–wheat cropping system. Energy-use efficiency of sweet basil–matricaria was higher (11.99) than that of the rice–wheat (11.43) cropping system. Highest benefit : cost ratio was recorded with sweet basil–matricaria (2.74), followed by chilli–garlic (2.42) cropping systems.

Key words: Crop diversification, Energy-use efficiency, Equivalent yield, Rice–wheat, Sodic soils, Time frame, Water-use efficiency

About 20% of the world's irrigated land is salt affected (Ghassemi *et al.* 1995). In India about 6.73 million ha land suffering from salinity and sodicity problems (Sharma *et al.* 2006). About 60% of the salt-affected soils are sodic and much of this land is farmed by small holders (Quadir *et al.* 2006). During last 2 decades a large area of salt-affected soils have been reclaimed through various government as well as non-government organizations and about 60–70% of the reclaimed salt-affected soils is occupied by rice–wheat cropping system. Though, it is widely adopted and is remunerative cropping system, but, it is observed that during the initial 3 years of reclamation, the productivity of salt-tolerant varieties is very high and after that it reduces with decreasing the sodicity levels. This is because of salt-tolerant varieties are having low yield potential in reclaimed sodic lands than the high-yielding varieties (Singh *et al.* 2008). Therefore, either salt-tolerant varieties need to be replaced by high-yielding varieties or diversify the cropping system with highly remunerative crops to compensate the reclamation cost and also to enhance the productivity of reclaimed sodic soils.

Though, rice–wheat is very remunerative cropping system but it created many serious ecological problems such as exhaustion of underground water, thereby resulting in depletion of groundwater from 15 cm to 80 cm every year. Due to continuous cultivation of rice–wheat cropping system in reclaimed sodic soils, the sustainability of the system is becoming questionable due to adverse effect on soil conditions, crop yield and factor productivity, increasing cost

[1]Principal Scientist (Agronomy), (e mail: ypsingh_5 @yahoo.co.in) ; [2]Senior Scientist (soil Science), (e mail: ranbirsingh_59@yahoomail.com); [3]Head and Principal Scientist (Agronomy), (e mail: dineshksharma1@rediffmail.com)

of cultivation and more weed infestation in wheat crop (Kumar and Yadav 1993, Nambiar and Abrol 1989). High crop response to N in sodic soil under rice–wheat cropping system further reduces the nitrogen pool of the soil (Swarup and Singh 1989a). Therefore, field experiment was conducted to determine the time frame for substitution of salt-tolerant varieties of rice and wheat through crop diversification.

MATERIALS AND METHODS

To determine the time frame for substitution of salt-tolerant varieties of rice and wheat with high-yielding varieties in sodic soils, field experiment was conducted from 2001 to 2005 at Research Farm, Regional Research Station, Central Soil Salinity Research Institute, Shivri, Lucknow, Uttar Pradesh, located at 26° 47′ N latitude and 80° 46′ E longitude at an elevation of 120 m above mean sea level during 2001–02 to 2004–05. The mean annual rainfall was 800 mm and more than 80% occurs during the monsoon season (July–September). Mean annual soil temperature varies from 18.6°C during winter and 32°C during summer (Fig 1). The soil was highly sodic with *p*H (1 : 2 soil: H_2O) 10.5, EC 1.43 dS/m and ESP 89 having low organic carbon (0.80 g/kg) and available N (94 kg/ha), medium in available P (25 kg/ha) and rich in exchangeable K (237.44 kg/ha) at 0–15 cm soil depth. The gypsum requirement (GR) of the experimental soil was determined by Schoonover (1952) method at the time of initiating the experiment (2001–02) was 30.8 tonnes/ha (Table 1). The experiment was laid out in split-plot design in a plot size of 10 m × 5 m keeping 4 levels of gypsum (0, 15, 25 and 50% of gypsum requirement) in main plots and 2 salt-tolerant varieties ('CSR 13' and 'KRL 19') and non-salt tolerant traditional high-yielding varieties ('Pant 4' and 'PBW 343') each of rice and wheat in sub-plots with 4 replications. As per treatments, gypsum was incorporated once in surface soil up to 10 cm depth in June 2001 and about 10 cm water was ponded in the plots for 10

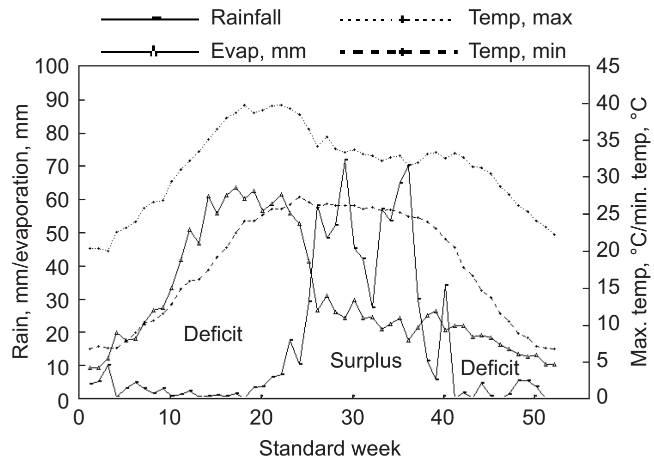

Fig 1 Climatic parameters of the study area

Table 1 Changes in soil properties due to gypsum levels and varieties of rice and wheat

Soil properties	Control		15%GR		25%GR		50%GR	
	V_1	V_2	V_1	V_2	V_1	V_2	V_1	V_2
2001–02								
*p*H (1 : 2)	10.18	10.24	9.95	9.98	9.50	9.58	9.22	9.40
EC (1 : 2) (dS/m)	0.97	1.01	0.64	0.88	0.67	0.69	0.65	0.69
ESP	82.10	87.21	72.62	75.43	60.00	63.67	45.50	52.76
O C (g/kg)	0.84	0.81	1.04	0.86	1.08	0.90	1.10	1.00
2002–03								
*p*H (1 : 2)	10.01	10.04	9.61	9.75	9.30	9.40	9.12	9.22
EC (1 : 2) (dS/m)	0.82	0.82	0.50	0.74	0.59	0.63	0.53	0.67
ESP	80.03	82.60	62.56	66.64	52.65	54.85	42.61	45.43
O C (g/kg)	0.86	0.84	1.06	0.88	1.10	0.95	1.15	1.16
2003–04								
*p*H (1 : 2)	9.88	10.01	9.46	9.51	9.21	9.34	9.00	9.10
EC (1:2) (dS/m)	0.76	0.82	0.60	0.66	0.56	0.62	0.48	0.54
ESP	72.23	75.12	55.24	57.32	45.40	45.70	32.00	34.43
O C (g/kg)	0.90	0.86	1.06	0.90	1.18	1.00	1.20	1.20
2004–05								
*p*H (1 : 2)	9.84	9.88	9.33	9.44	9.12	9.18	8.87	8.91
EC (1 : 2) (dS/m)	0.50	0.47	0.30	0.50	0.50	0.44	0.35	0.35
ESP	64.20	72.50	45.20	52.30	30.00	36.40	20.00	24.50
O C (g/kg)	0.90	0.88	1.10	1.00	1.20	1.10	1.40	1.20
Infiltration rate (mm/day)	4.80	4.60	7.00	7.00	11.30	11.00	19.30	19.00
Alkaline $KMnO_4$-N (kg/ha)	115.60	97.80	192.50	132.50	192.50	186.72	201.65	192.60

V_1, Salt-tolerant varieties of rice and wheat; V_2, traditional high-yielding varieties of rice and wheat days to displace the reaction products of Ca-Na exchange down the root zone. Thirtyfive-days-old seedling of rice was transplanted at 20 cm × 15 cm spacing while wheat was drilled at row spacing of 20 cm using a seed rate of 120 kg/ha. The recommended dose of N for sodic soils, i e 150 kg/ha and zinc sulphate @ 25 kg/ha to rice and 150 kg N/ha to wheat, was applied uniformly in all the treatments. Half dose of nitrogen to both rice and wheat along with full dose of zinc sulphate ($ZnSO_4$) to rice was applied as basal and remaining half of N was applied in 2 equal splits, i e at 30 and 60 days after transplanting and to wheat at 21days (crown root initiation) and 45 days after sowing. About 7.5 cm depth of irrigation water in rice was given 2 days after disappearance of ponded water (Singh *et al.* 2009) and 6 light and frequent irrigations in wheat at crown root initiation, tillering, late jointing, flag leaf initiation, milking and dough stages. The net plot area (40 m^2) was harvested and yield was recorded. Soil samples were collected after harvesting of wheat crop every year and analyzed to monitor the changes in soil physico-chemical properties. The organic carbon was determined by Walkley-Black method (Jackson 1973). Double concentric infiltrometer cylinders were used to measure the infiltration rate (Brechtel 1976).

After 4 years when the soil was partially reclaimed, the experiment on crop diversification to enhance the productivity of sodic soils was conducted on a soil having pH_2 9.2, EC_2 1.43 dS/m and organic carbon 0.10%. The experiment consisted of 4 cropping systems, viz S_1, rice–wheat (control); S_2, sorghum (*Sorghum bicolor* L. Moench)–berseem (*Trifolium alexandrinum* L.) (fodder-based); S_3, sweet basil (tulsi) – matricaria (Medicinal and aromatic crop-based) and S_4, chilli (*Capsicum annum* L.)–garlic (*Allium sativum* L.) (spices-based). The crops were raised with recommended package of practices. N, P and K were applied through urea, single superphosphate and muriate of potash, respectively. Full dose of P and K and half dose of N were applied as basal and rest of the N was given as per the recommendation for the individual crop. Pre-sowing irrigation was applied after the harvest of rainy season crops to ensure good germination of winter crops. During rainy (*kharif*) season varieties of 'Pant 10' rice, 'SSG 59-3' sorghum, 'Sim somya' sweet basil and 'LCA 235' chilli and in winter (*rabi*) 'PBW 343' wheat, 'JB 2' berseem, 'Vallary' matricaria and 'Parvati' garlic, respectively were grown. The observations on growth parameters of rice and wheat were recorded at 30 days interval, yield attributes and yield were recorded at harvest. Similarly, in case of sweet basil, chilli and matricaria, the plant height, number of branches were taken at 30 days interval and inflorescence weight/plant, fresh leaves weight/plant in sweet basil, length of fruit and fruit yield in case of chilli, size of bulb and weight of bulbs in case of garlic were recorded at maturity. The sorghum and berseem fodder yields were calculated on the basis of 2 and 4 cuttings of these crops, respectively. Land-use efficiency value was calculated by taking total duration of crop (in individual cropping system) divided by 365 and production efficiency value was calculated taking total production in a system divided by total duration of crop in a system (Tomar and Tiwari 1990). Water-use efficiency was worked out in terms of yield (kg/ha cm of water used that included irrigation water applied and effective rainfall). Energy input and output was calculated using the energy equivalents (Mittal *et al.* 1985). Prevailing market price of crop produce and inputs were taken for economic analysis of different systems on the basis of equivalent yield.

RESULTS AND DISCUSSION

Soil improvement

After 4 years of rice–wheat cropping, the *p*H (1 : 2) of surface soil (0–15 cm) treated with gypsum @ 50% gypsum requirement reduced from 10.5 to 8.8, whereas *p*H (1 : 2) reduced to the level of 9.1 in the treatment where gypsum was applied @ 25% gypsum requirement. In plots where no gypsum was applied, the *p*H (1 : 2) of surface soil was reduced to 9.8. The *p*H (1 : 2) of surface soil (0–15 cm) due to combined effect of growing salt-tolerant varieties of rice and wheat after treating with 25 and 50% gypsum requirement was reduced to 9.07and 8.87, whereas with traditional varieties it reduced to 9.12 and 8.91. There was not much difference in soil *p*H due to varieties. The ESP of the surface soil was reduced from 89 to 30 where gypsum was applied @25% gypsum requirement and salt-tolerant varieties of rice and wheat were grown, however, it reduced to 36.4 in the treatments where traditional varieties were grown. Chhabra and Abrol (1977) have also reported the changes in ESP and improvement in physical properties of sodic soils with reduced dose of gypsum and cultivation of rice–wheat cropping system. As the level of gypsum increased to 50% gypsum requirement, the reduction in ESP was not significant between salt-tolerant and traditional varieties (Table 2). Varieties alone did not play a significant role in improving soil infiltration rate but due to synergistic effect of gypsum and salt-tolerant varieties it increased to 11.3 mm and 19.3 mm/day with 25 and 50% gypsum requirement doses over the initial rate of 0.08 mm/day. Acharya and Abrol (1991) have also reported considerable improvement in infiltration rate with the addition of gypsum in sodic soils. Combined effect of gypsum and salt- tolerant varieties of rice and wheat generated more organic acids, which mobilize the soil calcium to leach down the salts from the root zone. Addition of gypsum increased the organic carbon content of the soil. After 4 years of rice–wheat cropping combined with 25 and 50% GR doses, the organic carbon content of the surface soil increased to 1.20 and 1.40 g/kg, respectively over the initial value of 0.80 g/kg (Singh *et al.* 2009).

Determination of time frame

During the 3 consecutive years (2001, 2002 and 2003) salt-tolerant varieties of rice gave significantly higher yields

Table 2 Yield, water-use and water-expense efficiency of different cropping systems

Cropping systems		Yield (tonnes/ha)		Rice equivalent yield (tonnes/ha)	Quantity of water used (cm)	Water-use efficiency (kg/ha cm)
		Kharif crop	*Rabi* crop			
S_1	Rice–wheat	4.04	3.33	7.74	125.65	61.59
S_2	Sorghum–berseem	29.62	36.85	9.28	115.65	80.24
S_3	Sweet basil–matricaria	0.074*	0.80*	14.21	100.65	141.18
S_4	Chilli–garlic–garlic	1.57	2.85	12.91	85.65	150.72
	CD (*P*=0.05)			0.65		

* Oil yield of sweet basil and dry flower yield of matricaria

Sale price of produce: rice @ 540/100 kg, Sorghum fodder@ ₹ 70/100 kg, sweet basil oil @ 500/litre, Chilli @ ₹ 800/100 kg, wheat @ 600/100 kg, matricaria flower @ 52.50/kg and garlic@ ₹ 2 000/100 kg.

at higher dose of gypsum. The yield difference between salt-tolerant and traditional high-yielding varieties of rice 'CSR 13' and 'Pant 4' during 2001 at 0, 15, 25 and 50% GR doses was 0.25, 1.16, 0.61 and 0.52 tonnes/ha, respectively. It is because of high yield potential of salt-tolerant varieties under high sodicity conditions (Mishra *et al.* 1992). During 2002, the yield difference between these 2 varieties narrowed down to 0.17, 0.53.0.62 and 0.42 tonnes/ha. During 2003, when the soil *p*H reduced to the levels of 9.8, 9.4, 9.2 and 9.0, the yield difference between salt-tolerant and traditional varieties reduced to the extent of 0.11, 0.42, 0.41 and 0.20 tonnes/ha, respectively. After 3 years of experiment (2004) salt-tolerant variety gave significantly higher yields up to 15% gypsum requirement dose where *p*H remained high (9.4), while at 25% gypsum requirement dose the yield difference (0.20 tonnes/ha) was non-significant but at 50% gypsum requirement dose where *p*H reduced to 8.9, traditional variety 'Pant 4' gave significantly higher yield over the salt-tolerant variety 'CSR 13'. It is because of high production potential of traditional variety over salt-tolerant variety under reclaimed sodic soils (Singh *et al.* 2009) (Fig 2).

As regards the time frame for replacement of salt-tolerant wheat cultivars, it is observed that the yield difference between salt-tolerant and traditional high-yielding varieties at 25 and 50% gypsum requirement dose during 2001–02 and 2002–03 was 0.47, 0.53, 0.22 and 0.31 tonnes/ha, respectively. During third year (2003–04), when the soil was partially reclaimed (*p*H 9.2) the yield difference between salt-tolerant and traditional variety at 25% gypsum requirement reduced to 0.24 tonnes/ha which was not statistically significant. However at 50% gypsum requirement when *p*H is reduced to 9.0, the traditional variety 'PBW 343' gave significantly higher yield over the salt-tolerant variety 'KRL 19'. This is the right time for replacement of salt-tolerant varieties with traditional varieties when gypsum is applied @ 50% gypsum requirement. During 2004–05 when the *p*H of the soil at 25% gypsum requirement and 50% gypsum requirement reduced to 9.0 and 8.8, traditional variety 'PBW 343' super passed the salt-tolerant variety in terms of grain yields. Therefore, it is inferred that after application of gypsum @ 25% gypsum requirement, salt-tolerant variety of wheat should be grown for 4 years however, with 50% gypsum requirement salt-tolerant variety may be replaced with high-yielding varieties even after 3 years (Singh *et al.* 2009).

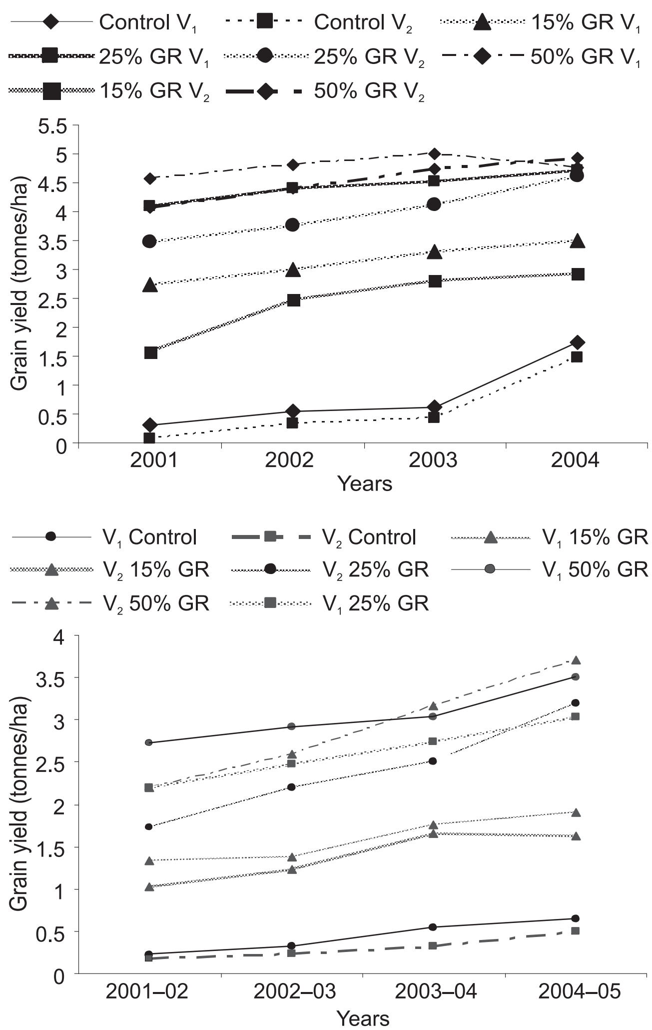

Fig 2 Time frame for the substitution of salt-tolerant varieties of (A) rice (B) wheat

Crop diversification for productivity enhancement

Crop yields: When the soil was partially reclaimed after 4 years of rice–wheat cropping system with 25 or 50% gypsum requirement doses, diversification study to enhance the productivity of reclaimed sodic soils revealed that traditional rice–wheat cropping system gave 7.37 tonnes/ha grain yields with lowest net returns of ₹ 29 861/ha. Sweet basil–matricaria cropping system yielded 0.074 tonnes/ha oil and 0.80 tonnes/ha of flower, respectively was most economic and fetched net profit of ₹ 50 222/ha with highest benefit : cost ratio of 2.74, followed by chilli–garlic with net profit of ₹ 32 510/ha and benefit: cost ratio of 2.42. Sorghum–berseem fodder-based cropping system recorded the highest fodder yields of 29.62 and 36.85 tonnes/ha, respectively with a net profit of ₹ 30 377/ha and benefit : cost ratio of 2.32 which is also higher than the rice–wheat cropping system (Table 3). Maximum rice equivalent yield (14.21 tonnes/ha) was recorded with sweet basil–matricaria cropping system, followed by chilli–garlic (12 tonnes/ha) and sorghum–berseem (9.28 tonnes/ha) and the lowest (7.74 tonnes/ha) with rice–wheat system. The higher rice equivalent yield in sweet basil–matricaria cropping system was because of high market price of sweet basil oil (Rs 500/litre) and matricaria flowers (Rs 52.50/kg) for medicinal and aromatic uses. Though, a good yield of sorghum (29.62 tonnes/ha) and berseem (36.85 tonnes/ha) was obtained from fodder-based cropping system, but it was not economical because of less rice equivalent yield. Sweet basil–matricaria cropping system got highest productivity potential in reclaimed sodic soils to give better returns (Thakur *et al*. 1989). Chilli–garlic, spices–based cropping system in reclaimed sodic soils also found to be more remunerative compared to the rice–wheat cropping system.

Water-use efficiency

Different cropping systems consumed varied quantity of irrigation water (Table 2). Maximum water (125.65 cm) was applied in rice–wheat and minimum (85.65 cm) in chilli–garlic cropping system. However, highest water expense efficiency (150.72 kg/ha cm) was obtained with chilli–garlic cropping system, followed by sweet basil–matricaria (141.18 kg/ha cm), sorghum–berseem (80.24 kg/ha cm) and rice–wheat (61.59 kg/ha/cm) cropping systems. The water requirements of sorghum–berseem, sweet basil–matricaria and chilli–garlic cropping systems were about 8.0, 19.8 and 31.8% less than the water requirement of rice–wheat cropping system.

Land-use and production efficiency

Sorghum–berseem cropping system achieved the highest land–use efficiency (78.35%) followed by rice–wheat (65.75%), chilli–garlic (564.38%) and sweet basil–matricaria (63.56%) cropping system. It is primarily due to the longer duration of winter crops. Berseem crop during winter season produced fodder for a longer time followed by wheat, garlic and matricaria. Production efficiency was highest (61.25 kg/ha/day) in sweet basil –matricaria cropping system, followed by chilli–garlic (54.93 kg/ha/day), sorghum–berseem (32.44 kg/ha/day) and rice–wheat (32.25 kg/ha/day) cropping system (Table 3). It is because of higher rice equivalent yield of sweet basil-matricaria than the other cropping systems.

Energetics

The total energy input in different cropping systems ranged

Table 3 Economics, land use and production efficiency of different cropping systems

Cropping system	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	Benefit : cost ratio	Production efficiency (kg/ha/day)*	Land-use efficiency (%)
S_1 Rice–wheat	25 978	55 839	29 861	2.14	32.25	65.75 (240)
S_2 Sorghum–berseem	19 837	50 214	30 377	2.32	32.44	78.35 (286)
S_3 Sweet basil–matricaria	28 778	79 000	50 222	2.74	61.25	63.56 (232)
S_4 Chilli–garlic	22 800	53 310	32 510	2.42	54.93	54.38 (235)

*Calculated on rice equivalent basis
Figures in parentheses are total duration of crops in that system

Table 4 Total energy (MJ × 10^3/ha) input and output of different cropping systems

Cropping system	Human labour	Diesel	N	P_2O_5	K_2O	Seed	Irrigation	Total input	Energy output	Energy efficiency
S_1 Rice–wheat	4.26	5.12	11.41	1.33	0.44	2.42	2.52	27.50	314.46	11.43
S_2 Sorghum–berseem	5.80	4.34	7.63	1.11	0.30	1.18	1.68	22.04	262.62	11.91
S_3 Sweet basil–matricaria	7.68	3.14	9.42	1.21	0.42	0.52	1.34	23.73	284.63	11.99
S_4 Chilli–garlic	6.09	2.89	8.43	1.31	0.48	1.69	1.21	22.10	213.52	9.66

from 22.04 to 27.50×10^3 MJ/ha (Table 4). In general, nitrogen accounted for single largest share of energy input, followed by diesel and human labour. The energy input through seed, phosphatic and potassic fertilizers and irrigation was of lower magnitude. Sweet basil–matricaria cropping system gave the highest energy-use efficiency (11.99) while the lowest was observed in chilli–garlic (9.66) cropping system. Though, the total energy output was high in rice–wheat (314.46×10^3 MJ/ha) cropping system but due to higher total energy (27.50×10^3 MJ/ha) the energy-use efficiency was less than sorghum–berseem and sweet basil–matricaria cropping systems. Similar findings were observed by Subbiah *et al.* 1995.

Economics

As the experiment was conducted with different cropping systems, consisting of crops of diverse nature, it is worthwhile to compare cropping systems on the basis of gross returns, net returns and benefit : cost ratio. Economics of different cropping systems was compared which revealed that the highest cost of cultivation (Rs 28 778/ha) was incurred in sweet basil–matricaria cropping system because of higher laboure requirement for picking the matricaria flowers, followed by rice–wheat (Rs 25 978/ha), chilli–garlic (Rs 22 800/ha) and sorghum-berseem (Rs 19 837/ha). However, maximum net returns (Rs 50 222/ha) was obtained from sweet basil–matricaria, followed by chilli–garlic (Rs 32 510/ha), sorghum–berseem (Rs 30 377/ha) and rice–wheat (Rs 29 861/ha) cropping systems. Comparison of benefit : cost ratio (net returns : cost of cultivation) revealed that maximum benefit: cost ratio (2.74) was obtained from sweet basil–matricaria, followed by chilli–garlic (2.42), sorghum–berseem (2.32) and rice–wheat (2.14) cropping systems (Table 3). These results confirm the findings of Roy bardhan *et al.* (1999).

On the basis of 5 years study it is concluded that with the application of reduced dose of gypsum (25% gypsum requirement) salt-tolerant varieties of rice should be replaced with high-yielding varieties after 4 years and of wheat after 3 years. If the gypsum is applied @ 50% gypsum requirement, salt-tolerant variety of rice should be replaced with high-yielding varieties after 3 years and wheat after 2 years or diversify the rice–wheat cropping system with highly remunerative medicinal and aromatic crops like sweet basil in *kharif* and matricaria in *rabi* to enhance the productivity potential of reclaimed sodic soils and to save the natural resources.

REFERENCES

Acharya C L and Abrol I P. 1991. Soil-water relation and root-water extraction in alkali soils. *Bulletin* **16**: CSSRI, Karnal.

Brechtel H M. 1976. Application of an inexpensive double ring infiltration: hydrological techniques for upstream conservation. *Conservation guide 2*, Food and Agricultural Organization (FAO), Rome.

Chhabra R and Abrol I P. 1977. Reclaiming effect of rice grown in sodic soils. *Soil Science* **124**: 49–55.

Ghassemi F, Jakeman A J and Nix H A.1995. *Salinisation of Land and Water Resources: Human Causes, Extent, Management and Case Studies*. CABI Publishing: Wallingford.

Jackson M L. 1973. *Soil Chemical Analysis*, Prentice Hall of India Private Ltd, New Delhi.

Kumar Alok and Yadav D S. 1993. Effect of long term fertilization on soil fertility and yield of rice-wheat cropping system. *Journal of Indian Society of Soil Science* **41** (1): 178–80.

Mittal V K, Mittal J P and Dhawan K C. 1985. Research digest on energy requirements in agricultural sector. (*in*) *Energy Requirement Scheme Report*, Indian Council of Agricultural Research, New Delhi.

Nambiar K K M and Abrol I P. 1989. Long term fertilizer experiments in India: an overview, *Fertilizer News* **34** (4):11–20.

Qadir M, Noble A. D, Schubert S, Thomas R J and Arslan A. 2006. Sodicity induced land degradation and its sustainable management: problems and prospects. *Land Degradation and Development* **17**: 661–76. DOI: 10.1002/ldr.751.

Roy Bardhan S K, Walker T, Khatana V S, Saha N K, Verma V S, Kadian M S Haverkort A J and Bowen W. 1999. Identification of potato production in rice based cropping system: a rapid rural appraisal in west Bengal. (*in*) *Impact on a Changing World*. *International Potato Centre Programme Report*, pp 205–12.

Sharma R C, Singh Ranbir, Singh Y P and Singh Gurbachan. 2006. Sodic Soils of Shivri Experimental Farm: Site characteristics, reclaimability and use potential for different land uses. *CSSRI Bulletin*, pp 1–32.

Singh Ranbir, Singh Y P, Yaduvanshi N P S and Sharma D K. 2009. Effect of irrigation scheduling and integrated nutrient management on yield of rice–wheat system and properties of reclaimed sodic soils. *Journal of the Indian Society of Soil Science* **57** (3): 280–6.

Singh Y P, Singh Ranbir, Sharma DK and Gangwar N P. 2008. Alternate options to rice–wheat cropping system for partially reclaimed sodic soils of Uttar Pradesh. *Current Science* **95** (5): 667–70.

Singh Y P, Singh Ranbir, Sharma D K, Nayak A K, Mishra V K and Singh Gurbachan. 2009. Synergy of reduced gypsum and salt tolerant varieties: A low cost sodic soil reclamation technology. *Technical bulletin*: CSSRI/Lucknow/2009/3 pp 28.

Singh Y P, Singh Ranbir and Sharma D K 2009. Combined effect of reduced dose of gypsum and salt tolerant varieties of rice (*Oryza sativa*) and wheat (*Triticum aestivum*) on rice–wheat cropping system in sodic soils. *Indian Journal of Agronomy* **54** (1): 24–8.

Subbiah P, Gopalsundaran P, Palaniappan.1995. Energetics and energy use efficiency of intensive cropping systems. *Indian Journal of Agronomy* **40**: 398–402.

Schoonover W R. 1952. *Examination of Soils for Alkali*. University of California, Extension Service, Berkely, California, USA.

Swarup A and Singh K N. 1989. Effect of 12 years rice–wheat cropping and fertilizer use on soil properties and crop yields in a sodic soil. *Field Crops Research*. **21**: 277–87.

Thakur R S Puri H S and Hussain A. 1989. Major medicinal plants of India, pp 338. CIMAP (CSIR), Lucknow.

Tomar S S and Tiwari A S. 1990.Production potential and economics of different cropping systems. *Indian Journal Agronomy* **35** (1&2): 30–5.