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Feasibility of different crop rotations for cultivation in salt affected soils

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Abstract: Crop rotation can be used as an effective technique for managing salt-affected soils, however selection of suitable crop rotation at farmer field is very intricate decision which depends on expected net revenue, available resources and preserving the soil quality. In this perspective a study was conducted to evaluate a suitable crop rotation scheme for salt affected soils in term of economic value and improving the soil health. Seven crop rotation used were; T_1 = Wheat-Rice, T_2 = Wheat-Sesamum, T_3 = Ispagol-Rice, T_4 = Ispagol-Qulfa, T_5 = Tukhum-e-blangoo-Qulfa, T_6 = Ajwain-Niazboo, T_7 = Saunf-Podina. A moderately salt affected field {pH_s = 8.65, EC_e 5.20 dS m^{-1}, SAR = 27.73 (mmol $l^{-1})^{1/2}$} was selected. The experimental design was randomized complete block design (RCBD) with three replications having plot size of 4 m x 6 m. Results of two years study showed that maximum grain yield was recorded by rice wheat rotation and maximum net income (208352 Rs. ha^{-1}) and BCR (4.72) was also observed in rice-wheat crop rotation over all other crop rotations. With respect to ameliorative affect, rice- wheat rotation also showed a significant positive impact on chemical properties of salt affected soil. Therefore, it is suggested that rice wheat crop rotation is the most suitable and economically attractive cropping scheme in salt affected soil which has potential to provide better long-term income to farmers, improve soil health and combat soil deterioration caused by salinity.

Key words: crop rotation; rice; wheat; salinity; cost benefit

Primernost različnih kolobarjev za pridelavo na slanih tleh

Izvleček: Kolobarjenje lahko uporabimo kot učinkovito tehniko za obvladovanje učinka slanosti tal, vendar je izbira ustreznega kolobarjenja za kmeta zelo zapletena odločitev, ki zavisi od pričakovanega neto dohodka, razpoložljivih sredstev in ohranjanja kakovosti tal. V povezavi s to tematiko je bila izvedena študija, katere namen je bil ovrednotiti primernost različnih načinov kolobarjenja na slanih tleh z ekonomskega vidika in vidika izboljšanja uporabnosti tal. Uporabljenih je bilo naslednjih sedem načinov kolobarjenja: T1 = pšenica (*Triticum aestivum* L.) – riž (*Oryza sativa* L.), T2 = pšenica – sezam (*Sesamum indicum* L.), T3 = indijski trpotec (*Plantago ovata* Forssk.) - riž, T4 = indijski trpotec - navadni tolščak (*Portulaca oleracea* L.), T5 = lalemancija (*Lallemantia royleana* Benth. in Wall.) - navadni tolščak, T6 = iranska kumina (*Carum copticum* L.) - navadna bazilika (*Ocimum basilicum* L.), T7 = navadni komarček (*Foeniculum vulgare* Mill.) - poprova meta (*Mentha piperita* L.). Izbrana so bila zmerno slana tla (pHs = 8.65, ECe = 5.20 dS m^{-1}, SAR = 27.73 (mmol $l^{-1})^{1/2}$). Poskus je bil zasnovan v naključnem bločnem razporedu (RCBD) s tremi ponovitvami in velikostjo parcelic 4 m × 6 m. Rezultati dvoletnega poskusa so pokazali, da je bil v kolobarju riža s pšenico dosežen največji pridelek zrnja in največji neto dohodek (208352 Rs. ha^{-1}) kot tudi največji količnik med stroški in prihodkom (BCR; 4.72). Kolobar riža s pšenico je pokazal tudi značilne pozitivne učinke na kemijske lastnosti slanih tal. Zaradi naštetega se za načrtovanje rotacije poljščin na slanih tleh priporoča kolobar riža s pšenico kot najbolj primeren in ekonomsko najbolj obetaven, saj ima večji potencial dolgoročnega zagotavljanja prihodkov kmetov, izboljšuje lastnosti slanih tal in zmanjšuje verjetnost njihovega slabšanja.

Ključne besede: kolobar; riž; pšenica; slanost; stroški/prihodki

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1 INTRODUCTION

A key challenge of 21st century agriculture is to provide the food, fiber and fuel for an expanding population while preserving the soil fertility and providing adequate farm profitability to farmers (Robertson and Swinton, 2005). Furthermore, agricultural land loss due to salinity is one of the main problems to sustainable agriculture as approximately 20 % of the world's cultivated land are salt affected (Sumner, 2000). In general, continued irrigation with poor quality ground water, poor infield management and a deficient drainage system are main causes of expansion of land salinization (Gehad, 2003). So in current scenario salt-affected soils are of growing importance to meet food demand of growing population and this situation necessitates some forward planning and need to find out several management and agronomic practices that work satisfactory for utilizing and preserving this natural resource (Gehad, 2003).

Rice (*Oryza sativa* L.), cultivation started nearly 11,500 years ago (Gnanamanickam, 2009) and approximately half of the world's population consumed the rice as staple food (Ma et al., 2007). To ensure food security for the expanding population, rice production should be increased by 50 % in rice consuming countries (Jinni and Joseph, 2017). Wheat (*Triticum aestivum* L.), is also a main vegetable protein source and is cultivated all around the world due to its adaptation to a various range of climates. Globally it is a major food crop, which is cultivated on approximately 200 million hectares with an average production of 600 million tons (Rajarm & Braun, 2006). Medicinal plants are also becoming increasingly popular in modern society and are used all over the world as natural alternatives to synthetic chemicals (Wyk & Wink, 2004). It may be worthwhile to explore potential of medicinal plants for salt affected soil, which may be beneficial for mankind. Previously many researchers have described the economical and medicinal importance of several halophytes (Dagar, 1995). Consequently, concerted research efforts are required for their immense potential to be planted on salt affected soils as valuable resource and cash crop on an urgent basis.

Crop rotation is an agricultural practice, which implicates cultivation of different crops on same field. Selection of suitable crop rotation at farmer field is very intricate decision. Economists assume that farmers tend to pursue activities that improve their utility, or well-being, generate revenue, lessen the monetary and physical risk, decrease labor demands, and are comfortable or pleasurable (Bowman and Zilberman, 2013). One of the main issues influencing crop production choices by farmers is the expected market price of selected commodity and the resulting estimated net revenue, in addition to the relative economic risk associated with production of potential commodities (Huirne et al., 2000). A farmer's earnings and capacity to achieve credit, farming systems, skill and technologies and willingness to invest in new crops will also influence the choice of crops (Knowler and Bradshaw, 2007; Salassi et al., 2013). In a study consisting of different crop rotation Dogan et al. (2008) reported that wheat and sunflower using as main crop were more profitable rotation system under rain fed conditions having net profit of \$474 and \$482 ha^{-1} year^{-1}, respectively. Likewise, Nel and Loubser (2004) stated that crop rotation consisting of sunflower, soyabean were most effective rotations with maximum net while mitigating financial risk. Similarly, a field trail showed that inclusion of oilseeds crop in cereals generate the maximum net return, reducing the financial risk through improved production stability (Dhuyvetter et al., 1996). To evaluate the economic assessment of different crop rotation consisting of: corn–soybean–corn (CSC), alfalfa–alfalfa–corn (AAC), continuous corn (CCC), soybean–wheat–corn (SWC), soybean–corn– corn (SCC) and soybean–alfalfa–corn (SAC). Goplen et al. (2018) reported that alfalfa–alfalfa–corn (AAC) was most dominant crop rotation with the highest net return of \$919 ha^{-1} yr^{-1}, mostly due to more stable prices of alfalfa. Jat et al. (2012) studied the economic performance of ten rice-based cropping sequences. Results revealed that rice - fenugreek - okra was most productive (25.73 t ha^{-1}) cropping system with maximum return of (96,286 Rs ha^{-1}).

However, in salt affected soils there is need to combine profitability in combination with other production factors like soil remediation, soil fertility and soil physical and chemical properties (Popp et al., 2005; Yao et al. 2013). Furthermore, crop rotation could be used as an alternative approach to improve soil health and combat soil deterioration. It improves soil structure (Yazar, 2008), increases soil organic matter (Bremer et al., 2008; Bhatti and Khan, 2012) and water use efficiency (Tanaka et al., 2005), improves crop nutrient use efficiency (Karlen et al., 1994), reduces grain yield variability (Varvel, 2000) and improves grain quality (Kaye et al., 2007).

Furthermore, when good quality water supplies are limited a suitable crop rotation is the only means for managing salt-affected soils and maintaining crop yields (Kaur et al., 2007). Crop rotation resulted in several improvements, in soil physical and chemical properties and is also suggested for salt affected soil, especially when crops with varying degrees of salinity tolerance are used (Lacerda et al., 2011). For suitable crop rotation in salt affected soils, selected crop should be either salt tolerant or tolerant cultivars must be selected from sensitive or medium tolerant crops with high economic value (Ouda et al., 2016; Kishk, 2000). Likewise, appropriate crop rotation in salt-affected soils can accelerate the reclamation process by reducing evaporation and upward transport of salt in the soil (Brady and Well, 2008).

Abro and Mahar (2007) reported that in rice-wheat cropping system, salinity indicators like soil EC_e, pH and SAR were significantly lowered after the rice harvest, however, a minor increase in EC_e and pH were recorded whereas, the SAR levels dwindled further after wheat harvest. Similarly in a study Liu et al. (2013) reported that the rice-barley crop rotation lowered soil EC_e after a reclamation time of more than 10 years. Zhang and He (2004) found that rice plantation resulted the addition of soil organic matter. The paddy soil management for 50 years favored the enhancement of soil organic carbon and decreased the concentrations of Ca, Mg, and Na (Chen et al., 2011). Fu et al. (2014) found that rice-barley crop rotation had more ameliorative effect on soil properties and significantly decreased the pH value than cotton-barley crop rotation system at the same year. Similarly, in a study Zou et al. (2011) concluded that the management of rice crop increased the accumulation of organic matter, which tends to converge soil pH to neutral. In addition, leaching effects of irrigation reduces the soil salinity (Iost et al., 2007; Fu et al., 2012).

So, keeping the all above facts in consideration the work presented in this paper was designed to evaluate a suitable crop rotation scheme for salt affected soils which will not only benefit the overall productivity and profitably of the farm but also improve the soil health.

2 MATERIAL AND METHODS

This field trial was conducted for two successive seasons from 2011-12 to 2012-13 at Soil Salinity Research Institute Pindi Bhattian. A moderately salt affected field {pH of soil saturated past (pH_s) = 8.65, electrical conductivity of soil extract (EC_e) = 5.20 dS m^{-1}, sodium absorption ratio (SAR) = 27.73 (mmol $l^{-1})^{1/2}$} was selected. The experimental design was randomized complete block design (RCBD) with three replications having plot size of 4 m x 6 m. The cropping seasons were Kharif (June– September) and Rabi (October–March). Cropping scheme used was as under:

Rabi crops were sown during the last week of November during 2010-11 and 2011-12 and Kharif crops were sown in last week of June during 2011 and 2012 in the same field. All cultural and management practices were carried out uniformly as and when required. Grain yield of each crop was recorded at maturity, whereas, for qulfa and podina biomass yield of economic value was noted. After harvesting of each crop, composite soil samples were collected for analysis of pH, EC_e and SAR. All the soil analysis was carried out following the method of U.S. Salinity Laboratory Staff (1954). In order to appraise the economic feasibility of different crop rotation total income was estimated by using existing price of each crop in local markets. Net income was derived subtracting the total expenses from total income and benefit: cost ratio (BCR) was computed by dividing gross income with total expenses (Shah et al., 2013). Collected data was subjected to analysis of variance following the method of Steel et al. (1997) to sort out significant differences among treatments at 5 % probability level.

3 RESULTS

3.1 RABI 2011-12

Data in Table 1 revealed that during first Rabi season (2011-12) maximum yield was produced by wheat crop (2.04 and 1.93 t ha^{-1}) in T_1 and T_2 respectively followed by ispagol with grain yield of 0.39 and 0.38 t ha^{-1} in T_3 and T_4 respectively. While minimum yield of 0.31 t ha^{-1} was recorded in ajwain. With respect to economic value maximum return of Rs. 55716 and 51618 ha^{-1} was earned by wheat crop in T_1 and T_2 respectively which was statistically non-significant ($p < 0.05$) with economic value of ajwain (Rs. 49600). Minimum economic value was observed in ispagol with Rs. 36486 ha^{-1}.

Treatments	Crop rotation	Rabi crops	Kharif crops
T_1	Wheat-Rice	Wheat (*Triticum aestivum* L.)	Rice (*Oryza sativa* L.)
T_2	Wheat-Sesamum	Wheat (*Triticum aestivum* L.)	Sesamum (*Sesamum indicum* L.)
T_3	Ispagol-Rice	Ispagol (*Plantago ovata* Forssk.)	Rice (*Oryza sativa* L.)
T_4	Ispagol-Qulfa	Ispagol (*Plantago ovata* Forssk.)	Qulfa (*Portulaca oleracea* L.)
T_5	Tukhum-e-blangoo-Qulfa	Tukhum-e-blangoo (*Lallemantia royleana* Benth. in Wall.)	Qulfa (*Portulaca oleracea* L.)
T_6	Ajwain-Niazboo	Ajwain (*Carum copticum* (L.) Link.)	Niazboo (*Ocimum basilicum* L.)
T_7	Saunf-Podina	Saunf (*Foeniculum vulgare* Mill.)	Podina (*Mentha piperita* L.)

Table 1: Yield and economic analysis of rabi crops 2011-12

Treatments (Crop Rotation)		Crop	Yield (t. ha^{-1})	Economic Value (Rs.)
T_1	Wheat-rice	Wheat	1.93 A	51618 AB
T_2	Wheat-sesamum	Wheat	2.04 A	55716 A
T_3	Ispagol-rice	Ispagol	0.39 B	39778 CD
T_4	Ispagol-qulfa	Ispagol	0.38 B	36486 D
T_5	Tukhum-e-blangoo-qulfa	Tukhum-e-blangoo	0.36 B	41233 CD
T_6	Ajwain-niazboo	Ajwain	0.31 B	49600 AB
T_7	Saunf-podina	Saunf	0.33 B	45433 BC

Means sharing the same letters are statistically similar at $p \leq 0.05$

3.2 KHARIF 2012

During Kharif season (2012) the highest yield of 2.32 and 2.24 t ha^{-1} was ensued by rice in T_1 and T_3 respectively followed by grain yield of 0.42 t ha^{-1} produced by niazbo which was statistically ($p < 0.05$) alike with yield of podina, qulfa and sesamum. As far as economic value of kharif crops was concerned maximum economic value (Rs. 71852 ha^{-1}) was observed in rice crop however it was statistically insignificant ($p < 0.05$) with qulfa and niazbo. Minimum economic value was recorded in sesamum (Rs. 37742 ha^{-1}).

3.3 RABI 2012-13

Data (Table 3) depicted that during 2nd Rabi season maximum yield was produced by wheat crop. Wheat produces the yield of 2.21 and 1.99 t ha^{-1} in T_2 and T_1 respectively. Minimum yield was produced by ajwain (0.32 t ha^{-1}) which was statistically ($p < 0.05$) non-significant with yield of ispagol and saunf. Data regarding the economic value showed that maximum economic value (Rs. 58049 ha^{-1}) was obtained by wheat crop followed by ajwain and both crops remain statistically ($p < 0.05$) non-

Table 2: Yield and economic analysis of Kharif crops 2012

Treatments (Crop Rotation)		Crop	Yield (t ha^{-1})	Economic Value (Rs. ha^{-1})
T_1	Wheat-rice	Rice	2.32 A	71852 A
T_2	Wheat-sesamum	Sesamum	0.38 B	37742 B
T_3	Ispagol-rice	Rice	2.24 A	69481 A
T_4	Ispagol-qulfa	Qulfa	0.31 B	69404 A
T_5	Tukhum-e-blangoo-qulfa	Qulfa	0.34 B	68455 A
T_6	Ajwain-niazboo	Niazboo	0.42 B	66868 A
T_7	Saunf-podina	Podina	0.35 B	49519 B

Means sharing the same letters are statistically similar at $p \leq 0.05$

Table 3: Yield and economic analysis of Rabi crops 2012-13

Treatments (Crop Rotation)		Crop	Yield (t ha^{-1})	Economic Value (Rs. ha^{-1})
T_1	Wheat-rice	Wheat	1.99 B	52285 B
T_2	Wheat-sesamum	Wheat	2.21 A	58049 A
T_3	Ispagol-rice	Ispagol	0.42 C	42445 C
T_4	Ispagol-qulfa	Ispagol	0.40 C	40153 C
T_5	Tukhum-e-blangoo-qulfa	Tukhum-e-blangoo	0.37 C	45900 C
T_6	Ajwain-niazboo	Ajwain	0.32 C	52267 B
T_7	Saunf-podina	Saunf	0.34 C	54767 AB

Means sharing the same letters are statistically similar at $p \leq 0.05$

Table 4: Yield and economic analysis of Kharif crops 2013

Treatments (Crop Rotation)		Crop	Yield (t ha^{-1})	Economic Value (Rs. ha^{-1})
T_1	Wheat-rice	Rice	2.08 A	88542 A
T_2	Wheat-sesamum	Sesamum	0.25 C	37500 C
T_3	Ispagol-rice	Rice	1.98 A	84292 A
T_4	Ispagol-qulfa	Qulfa	0.61 B	73833 AB
T_5	Tukhum-e-blangoo-qulfa	Qulfa	0.66 B	79833 A
T_6	Ajwain-niazboo	Niazboo	0.53 B	61333 B
T_7	Saunf-podina	Podina	0.30 C	36120 C

Means sharing the same letters are statistically similar at $p \leq 0.05$

significant from each other. While minimum economic value (Rs. 40153 ha^{-1}) was showed by ispagol.

3.4 KHARIF 2013

Data in table 4 displayed that during 2nd Kharif season maximum yield of 2.08 and 1.98 t ha^{-1} was produced by rice crop in T_1 and T_3 respectively followed by qulfa crop, while minimum yield (0.25 t ha^{-1}) was recorded in sesamum. Economic value data showed that maximum economic return of Rs. 88542 ha^{-1} was achieved by rice crop followed by qulfa crop, however, difference between to crop was not large enough to reach a level of significance ($p < 0.05$). Minimum economic value (Rs. 36120 ha^{-1}) was observed in podina crop.

3.5. SOIL PROPERTIES

Soil analysis data (Table 5) at the end of study showed that soil properties were also considerably affected by type of crop used in crop rotation. Among all the rotation rice-wheat crop rotation showed a minimum value (8.36) for soil pH followed by ispagol-rice rotation with pH value of 8.39. Maximum pH value (8.44) was noted in tukhum-e-blangoo-qulfa rotation. Similarly, rice crop also improved the salinity indicators i.e EC_e and SAR of soil. Minimum value of EC_e (3.87 dS m^{-1}) and SAR (20.96 mmol l^{-1})$^{1/2}$ were noted in rice wheat crop rotation. Whereas, maximum value (4.50 dS m^{-1}) of EC_e was observed in saunf-podina rotation and for SAR maximum value (24.80) was observed where ajwain-niazboo rotation was used.

3.6 ECONOMIC ANALYSIS

Economic analysis data (Table 6) at the end of 2 years study showed that different crop rotation in salt affected soils had significant effect on gross income, net income and benefit: cost ratio (BCR). Maximum net income (208352 Rs. ha^{-1}) and BCR (4.72) was recorded by rice-wheat crop rotation and minimum net income (128207 Rs. ha^{-1}) and BCR (3.10) was observed in wheat sesamum rotation.

4 DISCUSSION

Decision of suitable crop rotation scheme in salt af-

Table 5: Effect of different crop rotation on soil chemical properties at the end of experiment

Treatments (Crop Rotation)		pH_s	% decrese over initial value	EC_e (dS m^{-1})	% decrese over initial value	SAR (mmol l^{-1})$^{1/2}$	% decrese over initial value
T_1	Wheat-rice	8.36	3.35	3.87	25.57	20.96	24.41
T_2	Wheat-sesamum	8.40	2.89	4.32	16.92	22.4	19.22
T_3	Ispagol-rice	8.39	3.00	3.92	24.61	21.76	21.52
T_4	Ispagol-qulfa	8.43	2.54	4.46	14.23	23.8	14.17
T_5	Tukhum-e-blangoo-qulfa	8.44	2.42	4.44	14.61	24.12	13.01
T_6	Ajwain-niazboo	8.41	2.77	4.38	15.76	24.80	10.56
T_7	Saunf-podina	8.42	2.65	4.50	13.46	23.36	15.75

Table 6: Effect of different crop rotation on net income and benefit: cost ratio (BCR) at the end of study

Treatments (Crop Rotation)		Cost of production (Rs. ha^{-1})	Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	Benefit: costratio (BCR)
T_1	Wheat-rice	55945	264297	208352	4.72
T_2	Wheat-sesamum	60800	189007	128207	3.10
T_3	Ispagol-rice	61356	235995	174639	3.84
T_4	Ispagol-qulfa	55987	219876	163889	3.92
T_5	Tukhum-e-blangoo-qulfa	65344	235421	170077	3.60
T_6	Ajwain-niazboo	58650	230068	171418	3.92
T_7	Saunf-podina	55182	185839	130657	3.36

fected soil is very complex intrinsically region dependent task and should be based on salinity tolerance, economic value of the crop, impact on environment, generated revenue, available resources, food security and market conditions (Dogliotti et al., 2014 ; Smajgl et al., 2016). Crop rotation scheme on a farm is justified by preserving soil quality (Brankatschk and Finkbeiner, 2015; Nemecek et al., 2015), increased economic benefits (Dhuyvetter et al., 1996) improved soil properties (Peterson and Westfall, 2004), environmental perspective (Reckling et al., 2015), ensuring long term yield and soil fertility (Hennessy, 2006; Dury et al., 2011). Different crop rotation models have been evaluated in terms of agronomic as well as farm profitability in combination with their impact on soil health (Hulugalle et al., 2002; Popp et al., 2005).

Crop diversification in a cropping sequence generally reduces risk of failure through more stable yield and market price diversification as low income by one crop can be offset by high income of another crop in a given year (Meyer-Aurich et al., 2006; Nemecek et al., 2008). Zentner et al. (2002a) also reported that farmers who adopted diversified crop rotation earned more income.

Therefore, in this study we proposed the seven crop rotations for salt affected soil which should be acceptable to local farmers, can generate the income and contribute to food security and rural development. In developing countries one of most common factor for fast adoptability of a cropping sequence by farming community is expected market price and resulting net economic return of selected crop (Hurine et al., 2000; Salassi et al., 2013).

Nevertheless, viability and adoptability of cropping system does not depend on crop yield but also on efficiency in use of available resources (Moreno et al., 2011). Net return generated by a rotation is very critical because selection of a suitable crop affects the affects economic benefits (Jatoe et al., 2008; Martin and Hanks, 2009). In general, farmers tend to pursue activities which maximizes their farm profitability, reduced physical labor and financial risk, and are convenient and enjoyable (Bowman and Zilberman, 2013).

Salt stress rapidly reduces the plant growth due to osmotic stress and ion toxicity (accumulation of toxic Cl^- and Na^+ in cells of shoot) and ultimately the final yield of crops (Munns and Tester, 2008; Tamimi et al., 2016). The ability of a plant to tolerate salinity is a vital factor in plant productivity (Momayezi et al, 2009). Considering individual year yields, wheat was the most high yielding crop in Rabi season, while rice perform better among Kharif crops. These crops tolerate the salinity mainly two mechanisms, osmotic tolerance and ion exclusion (Munns and Tester, 2008; Roy et al, 2014) while, yield of other crops was low due to higher salinity sodicity problem and inefficient tolerant mechanisms. Also, rice-wheat rotation showed a preventive impact on soil salinity/sodicity build up and consequently crop yield was increased. Rice and wheat crop are previously reported as salt tolerant and can utilize to maximize the productivity and profitability of salt affected soils.

Economic circumstances of developing countries are compelling farmers to cultivate crops that generate high income, leading to cereal-dominated crop rotations (Sieling & Christen, 2015).

Economic performance of a crop rotation contributes to its adaptation and continuity but in general economic analysis studies of rotations are scarce (González et al., 2002). Many researchers study the economic performance of different crop rotations (Chen, 2009; Chen and Chen, 2011; Zhu et al., 2011).

Rice-wheat rotation is a popular crop rotation in southern and eastern Asia with an area of 24 to 27 million hectares (Wassmann et al., 2004). According to economic analysis of present study, rice wheat cropping scheme exhibited more benefit per hectare of crop and this rotation may provide maximum economic benefit to farmers in comparison to other. One of the plausible explanation for yield and revenue advantage of rice and wheat crops under salt affected soil might be their more salinity tolerance in comparison with other crops used in rotation (Yeo et al, 1990; Purushottam et al., 2012; Saringi et al., 2015; Hasan et al., 2015) coupled with market value and commercialization of these crops (Singh et al., 2014). More revenue generated by rice wheat crop rotation may be due to prevailing socio-economic conditions of the region (Livingston et al., 2012; Pare et al., 2015; Liu et al., 2016) as both crops are used as staple commodities and their market prices were less variable as compared to other crops in rotation. So adequate and high quality yield of rice and wheat with substantial net return contributes the rice- wheat rotation dominating all other rotations. According to González et al. (2013) wheat earned the income of US$1051 ha^{-1} and barley US$711 ha^{-1}, which are economically attractive and more than bean and sugar beet. Comparable results have been reported by Mellado et al. (2000), Stanger et al. (2008), and Hirzel (2011). Dominant and profitable crop rotations with reduced risk depend on prevailing conditions of specific regions (DeVuyst and Halvorson, 2004; Saharawat et al., 2010). Sánchez-Girón et al. (2004) also evaluated the economic performance of different crop rotations wheat-barley, wheat-vetch and barley-vetch for sixteen years and concluded that economic return of crop rotation depend upon the factors beyond control like market price and climate of the region that influence the variable like cost of production, quality and quantity of yield, and net income which are the main sources of variability or economic uncertainty. In a long term study of fifteen years Stanger et al. (2006) evaluated the effect of different nitrogen levels on seven crop rotation i.e. continuous alfalfa (*Medicago sativa* L.) (AA), corn-soybean-corn-oat with alfalfa seeding-alfalfa (CSCOaA), continuous corn (*Zea mays* L.) (CC), corn-alfalfa (CA), corn-corn-oat (*Avena sativa* L.) with alfalfa seeding-alfalfa-alfalfa (CCOaAA), corn-corn-corn-alfalfa-alfalfa (CCCAA) and corn-soybean (*Glycine max* (L.) Merr.) (CS). They reported that maximum return was earned by corn-soybean rotation at all nitrogen levels. Similarly Singh et al. (2011) study the productivity and economic performance of different crop rotation like rice-potato-green gram, rice-pea, rice-wheat, rice-wheat-sesbania, rice-lentil + mustard -cowpea, rice-chickpea, rice-lentil-cowpea, rice-maize + pea - cowpea, rice-mustard-green gram and rice-wheat-green gram. They concluded that rice-potato-green gram cropping system gave the highest productivity net return and benefit: cost ratio.

Similar findings were reported by Kaur et al. (2007) that paddy-based crop rotations were beneficial for salt affected soil and they also recommended the fallow-wheat cropping sequence as an alternative cropping scheme. In similar studies, the highest net income was obtained from wheat-rice rotations (Guan et al., 2011; Zentner et al., 2002), the rice-potato-sunflower sequence (Jaiswal et al., 1993) and rapeseed-common vetch + sunflower-wheat (Dogan et al., 2008). Our results are reinforced by earlier findings that not only the sequence, but also the choice of crops in the rotation influences the economic margin (Wilson et al., 2003; Jatoe et al., 2008). Economic benefits of different crop rotation have been reported by several researchers (Tzilivakis et al. 2005; Chen et al., 2015; Babulicova, 2016; Aminifar et al., 2017) which are in agreement with our findings.

4.1. SOIL PROPERTIES

Hence along with direct income generated, long term environmental impacts and sustainability of a cropping sequence must be also taken into account when determining its suitability for salt affected soil. Rotation type had substantial effects on soil health and qualities, results showed that all cropping sequences lowered the soil pH, EC_e and SAR at the end of study. Rice-wheat rotation showed maximum reduction of 3.35 % in soil pH, which may be ascribed to leaching of soluble salts and $CaCO_3$ resulting a rapid fall in pH value (Cui et al., 2012; Fu et al., 2014; Neugschwandtner et al., 2014; Mahmood et al., 2016). Results of this study are in agreement with finding of Abro and Mahar (2007) who found a significant decrease in salinity indicators i.e. pH, EC_e and SAR after the rice harvest, however, a slight increase in pH and EC_e were recorded while, the SAR levels decreased further after wheat harvest. Similarly, Gehad (2003) also reported rice wheat rotation as most suitable cropping pattern during reclamation of salt affected soil. Data also showed that rice wheat cropping pattern reduces EC_e and SAR upto 25.57 and 24.41 % respectively, which could be explained due to leaching effect of irrigation as rice crop required the frequent irrigation (Iost et al., 2007; Fu et al., 2012). Our results are supported by series of findings that cropping pattern revealed an absolute temporal trend on soil properties (Fu et al., 2014; Lazicki et al., 2016; King and Hofmockel, 2017). Similar findings were reported by Fu et al. (2012) and Liu et al. (2013) that the rice-barley cropping sequence decreased soil salinity after a reclamation time of more than 10 years. Furthermore, cultivation of rice favored the addition of soil organic matter and decreases the Na, Ca and Mg contents (Chen et al., 2011; Zhang and He, 2004) which tends to converge soil pH to neutral and improved the soil properties (Zou et al., 2011). In study conducted by Fu et al. (2014) they found that rice-barley crop rotation had more ameliorative effect on soil properties and significantly decreased the pH value than cotton-barley crop rotation system at the same year.

5 CONCLUSION

Utilization and remediation of marginally salt affected soil is a global challenge for sustainable agriculture. Optimizing the agricultural production from salt affected soil requires appropriate farmer's decision based on economic and environmental constraints. Finally results generated by current study suggested that rice-wheat crop rotation is the most suitable and economically attractive cropping scheme in salt affected soil which has potential to provide better long-term income to farmers, improve soil health and combat soil deterioration caused by salinity.

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