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Full Length Article

Gypsum and Farm Manure Application with Chiseling Improve Soil Properties and Performance of Fodder Beet under Saline-sodic Conditions

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Abstract

Soil and water salinity and sodicity is among the salient environmental stresses which impair productivity of all the arable crops. Damages induced by such stresses could be decreased by the application of certain soil amendments. Hence, a three-year field study was conducted to evaluate the effects of several amendments to improve growth of fodder beet (*Beta vulgaris* subsp. *vulgaris* cv. Kawai terma) grown in a saline-sodic field (EC_e = 5.05 dS m^{-1}, pH_s = 9.04 and SAR = 46.20 (mmol L-1)$^{1/2}$ and soil gypsum requirement (SGR) of 10.52 t ha^{-1} for 0-15 cm soil depth. The amendments included gypsum application at 100 and 50% of SGR, gypsum application at 25% of SGR + 10 t ha^{-1} farm manure (FM), chiseling + gypsum application at 25% of SGR, chiseling + gypsum at 25% of SGR + 10 t ha^{-1} FM and sulfur application equivalent to 50% of SGR. In control plot fodder beet was grown without any amendment. Analysis of three-year pooled data indicated that all the amendments significantly improved soil physical-chemical properties and fodder beet yield. However, data proved the supremacy of gypsum application at 100% of soil GR, and chiseling + gypsum at 25% of SGR + FM at 10 t ha^{-1} in improving soil properties like bulk density, organic matter, hydraulic conductivity, pH_s, EC_e, SAR and fodder beet root and shoot biomass than all the other amendments and the control. The effectiveness of amendments remained in the order: chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1} = gypsum at 100% of SGR > gypsum at 25% of SGR + FM at 10 t ha^{-1} > gypsum at 50% SGR > sulfur = gypsum at 50% of SGR > chiseling + gypsum at 25% of SGR > control. A considerable improvement in soil properties by growing fodder beet without any amendment indicated its potential to be used as an agent of biological reclamation of salt-affected soils. It is concluded that combined application of gypsum at 25% of SGR plus FM @ 10 t ha^{-1} with chiseling in salt-affected field effectively improved growth of fodder beet and reclaimed saline-sodic soil and have future prospects.

Keywords: Soil properties; Fodder beet; EC_e; SAR; Root growth; Saline-sodic soil

Introduction

Geographically, Pakistan is located in semiarid region of the world, and more than 6.67 m ha land of the country is subjected to salinity, which is about 1/3rd of total cultivated area, and makes the crop production uneconomical (Muhammed, 1990; Khan, 1998). Moreover, out of this 6.67 m ha salt-affected area, 3.77 m ha area is saline and 2.90 m ha area is saline-sodic/sodic (Khan, 1998) in Pakistan.

Soil salinity and/or sodicity affect many physiological and biochemical processes (photosynthesis, protein synthesis, nutrients uptake etc.) in plants, which lead to impaired growth and productivity of almost all arable crops (Qadir and Schubert, 2002; Farhoudi *et al*., 2012; Hussain *et al*., 2012, 2013). The major cation in exchange complex is Na^+, due to which saline-sodic soils endure deterioration in physical properties, like swelling, dispersion of clay, hard setting and surface crusting. All these combine ultimately to impede air and water movement, reduce plant-available water and also lessen the absorption of essential plant nutrients due to ionic antagonism (Suarez, 2001; Qadir and Schubert, 2002). Hence, it is compulsory to reduce hazardous effects of salinity and sodicity by proper integrative management practices. Moreover, improvement and utilization of such marginal lands are more critical for developing countries like Pakistan.

Sodic or saline-sodic soils are usually reclaimed by chemical methods (Qadir *et al*., 2007; Feizi *et al*., 2010). Leaching of Na^+ from root zone is the most familiar and useful methods for lowering its buildup in salt-affected soils

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(Ghafoor *et al*., 2008). The replaced Na^+ in consequence of Ca^{2+} application is either leached from root zone by excess irrigation, and/or taken up by crops (Qadir and Oster, 2002).

Use of deep tillage practices, chiseling in particular, are often helpful in improving soil permeability, infiltration rate and thus help in leaching of salts and reclaiming the saline soils (Miyamoto and Storey, 1995). Hence, gypsum applications tied with proper tillage is prerequisite for reclaiming saline-sodic soils. Earlier reports also highlighted the maximum improvement in hydraulic conductivity of soil with simulated sub-soiling and gypsum-saturated solution (Shahid, 1993). Likewise, addition of organic matter such as farmyard manure (FYM), green manure and municipal solid waste is an effective strategy for salt-affected soils remediation (Pang *et al*., 2010). Use of organic amendments may promote sustainability because of long-term ameliorative effects on chemical, physical and biological properties of soil (Ould-Ahmed *et al*., 2010). Mohamed *et al*. (2012) reported that irrigating at 7 d interval along with application of chisel-harrow and addition of FM recorded maximum fresh yield and root length of sorghum fodder.

Yield of nearly every conventional crop is drastically reduced in salt-affected soils; and therefore, introducing non-conventional salt tolerant fodder crops might be a suitable option, which contributes toward the basis of biological soil reclamation. Fodder beet is one of the promising winter forage crop which can grow successfully under limited water and nutrients supply (El-Sarag, 2013). It can tolerate high salinity during vegetative growth and could be cultivated successfully in saline soils (Niazi *et al*., 2000). It is used as animal fodder directly or stored in the soil without any damage.

Owing to the benefits of growing beets in salt-affected soils, a three-year field trial was conducted to assess improvement in soil physical and chemical properties of saline-sodic soil along with production of fodder beet by using different remedial strategies.

Materials and Methods

Description of Experimental Site

This field study was conducted for three consecutive years (2009–2010, 2010–2011 and 2011–2012) at Soil Salinity Research Institute, Pindi Bhattian, Pakistan. The experimental site was fairly uniform and saline-sodic in nature. Before the first sowing of first crop (2009–2010), the soil had EC_e = 5.05 (dS m^{-1}), pH_s = 9.04 and SAR = 46.20 (mmol L-1)$^{1/2}$ with soil gypsum requirement (SGR) of 10.52 t ha^{-1} for 0–15 cm soil depth).

Treatment Details

The remedial strategies included gypsum application at 100% (10.52 t ha^{-1}) and 50% of SGR, gypsum application at 25% of SGR + 10 t ha^{-1} farm manure (FM), chiseling + gypsum application at 25% of SGR, chiseling + gypsum at 25% of SGR + 10 t ha^{-1} FM and sulfur application equivalent to 50% of SGR. No amendment was added in the control plots. The experiment was laid out in randomized complete block design (RCBD) with three replications. The experiment was conducted in the same field for three consecutive years i.e., 2009–2010, 2010–2011 and 2011–2012, each year starting in November and ending in May.

Gypsum (80% pure, 30 mesh size) and sulfur were applied 30 days before sowing, followed by leaching with canal water at soil surface and maintaining a 7.5 cm water depth for 13 days and FM was applied 15 days before sowing of fodder beets in the respective plots. In the treatments having chiseling as amendment; soil was tilled with chisel plough to a depth of 0–25 cm once at start of experiment and before the application of gypsum and FM. Gypsum was broadcasted on the soil surface and water was applied at the depth of 7.5 cm for leaching of salts. Fodder beet (*Beta vulgaris* subsp. *vulgaris* cv. Kawai terma) was sown in rotation with rice. The seeds of fodder beet were sown on 45 cm a part ridges. The plants were spaced 25 cm apart while the plot size was 5.0 m × 4.5 m. Fertilizers were applied at the rate of 90, 100 and 50 kg ha^{-1} of nitrogen (N), phosphorus (P) and potassium (K) as urea, single super phosphate and sulphate of potash. Two third of N and whole of P and K were added at sowing time while remaining one-third N was applied 6 weeks after sowing. The fodder beet in each plot was treated with uniform agronomic practices to keep crop free from insect and diseases. Each year, the crop was harvested in May after six months of sowing.

Observations Recorded

Before the start of experiment, and after the harvest of fodder beet crop in each season, composite soil samples from each experimental plot were collected and were analyzed for determination of soil physical-chemical properties by following the methods as described by the US Salinity Lab. Staff (1954). Hydraulic conductivity was measured by using falling head hydraulic conductivity apparatus. Soil samples were air-dried, ground, and sieved through 2 mm sieve. Time of water application and time of initial outflow was recorded. Percolate was collected in a beaker, volume was measured and hydraulic conductivity was calculated as under:

$$K = Q\Delta L / tA\ \Delta H$$

Where, Q = volume of water passing through the material in time (t), A = area of soil column, and K= average hydraulic conductivity in soil interval (ΔL) over, which there is a hydraulic head difference (ΔH).

Soil organic matter was determined following Walkley (1947). Soil bulk density was measured according to Blake and Hartge (1986) using samples obtained by a manually operated tool. These cores were approximately 5 cm in diameter and 5 cm in length and 100 cm^3 in volume. These soil samples were oven-dried at 105°C to constant weight and bulk density was calculated as:

Bulk density (Mg m^{-3}) = Oven dry mass of soil (g)/Volume of soil (cm^3)

Electrical conductivity of the soil saturation extract was measured with the help of conductivity meter (WTW conduktometer LF 191). Soil pH of the saturation extract was measured by using pH meter (Microcomputer pH-vision cole parmer model 05669-20). The Na^+ contents were determined by flame photometer (digiflame code DV 710) while Ca^{2+} and Mg^{2+} were determined titrimetrically. Sodium adsorption ratio (SAR) was calculated as follows where ionic concentration of the saturation extracts is given in $mmol_e$ L^{-1}.

$$SAR = Na^+ / [(Ca^{2+} + Mg^{2+})/2]^{1/2}$$

Germination percentage was calculated as a ratio between total seedlings with seeds sown multiplied by 100. Ten randomly selected plants from each plot were used to compute the data regarding root length and diameter, shoot length and number of leaves per plant. To record root and shoot fresh weight, total plants in each plot were harvested after six months and weighed. The weighed mass of roots and shoots was converted into t ha^{-1}. Uniform sized samples of root and shoot were kept in oven at 80°C for three days to estimate the dry weights, which were then converted into t ha^{-1}.

Statistical and Economic Analysis

The data collected during three years was pooled up and statistically analyzed following analysis of variance (ANOVA) technique under randomized complete block design while the least significance difference (LSD) test was used to compare the differences among treatment means (Steel *et al*., 1997). In order to appraise the economic feasibility of various amelioration techniques used, an economic analysis was conducted. Total expenses of crop included the cost of amelioration techniques used, seed, seedbed preparation, sowing cost, irrigation, fertilizing, crop protection, weeding, harvesting and land rent. Gypsum, FM, chiseling and sulphur was applied once at the start of experiment. Total income was calculated by using existing price of beet fodder and tuber in local market of the country. Net returns was computed by deducting the total expenses from total income, whereas benefit: cost ratio (BCR) was worked out by dividing gross income with total expenses (Shah *et al*., 2013).

Results

All the remedial strategies, used to grow fodder beet under saline-sodic conditions, notably improved the soil chemical properties i.e., EC_e, pH_S, and SAR after three years of experimentation (Table 1). Among all the remedial strategies gypsum application at 100% of SGR and chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1} proved the best strategies to improve the soil EC_e, pH_S and SAR after three years of application (Table 1). Gypsum application at 100% of SGR, and chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1} lowered the soil pH_S by 6.64% and 6.42%; soil EC_e by 64.36% and 61.39% and SAR by 69.31% and 68.61%, respectively. However, with control the decrease in soil pH_S, EC_e and SAR was only 2.88%, 30.69% and 19.24%, respectively after three years (Table 1).

All remedial strategies substantially lowered bulk density, and improved hydraulic conductivity and organic matter contents of soil after three years (Table 2). Application of gypsum at 100% of SGR, and chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1} proved the best (Table 2). The gypsum application at 100% of SGR, and chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1} lowered the bulk density by 25.44% and 27.81%, respectively while control only lowered the bulk density up to 3.55%. Gypsum application at 100% of SGR, and chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1}, respectively improved the hydraulic conductivity by 170.58% and 185.29%, and soil organic matter by 46.81% and 48.94%, respectively (Table 2). The control plots recorded only 17.65 and 12.77% increase in hydraulic conductivity and soil organic matter (Table 2).

Analysis of three years pooled data showed that all the remedial strategies significantly differed regarding the germination and root traits of fodder beet grown (Table 3). All the remedial strategies used substantially improved germination of fodder beet compared with the control (Table 3). The gypsum application at 100% SGR and chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1} recorded 85% and 86% germination compared with 59% germination in the control (Table 3). Maximum root fresh weight (70.0 t ha^{-1}) and dry weight (17.47 t ha^{-1}) was obtained with gypsum applied at 100% SGR but it was at par where chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1} was applied. However, minimum fresh (53.0 t ha^{-1}) and dry weight (8.36 t ha^{-1}) of roots was for the control plots (Table 3). Maximum root length was recorded for gypsum applied at 100% SGR, and chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1} and was minimum for the control treatment (Table 3). Gypsum application at 100% SGR resulted in maximum root diameter but it was at par with gypsum at 50% SGR, gypsum at 25% SGR + FM at 10 t ha^{-1} and chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1} and the control treatment yielded the least (Table 3). Analysis of three years pooled data indicated that different remedial strategies had significant effect on shoot length, number of leaves per plant, and fresh and dry yield of fodder beet grown under saline-sodic conditions (Table 4). Maximum shoot length and number of leaves per plant

Table 1: Effect of different amelioration strategies on chemical properties of soil by the end of three years of experimentation

Treatments	pH_s		EC_e		SAR (mmol L^{-1})$^{1/2}$	
	2009-2010	2011-2012	2009-2010	2011-2012	2009-2010	2011-2012
Control	9.04	8.78 (-2.88)	5.05	3.50 (-30.69)	46.20	37.31 (-19.24)
Gypsum at 100% SGR	9.04	8.44 (-6.64)	5.05	1.80 (-64.36)	46.20	14.18 (-69.31)
Gypsum at 50% SGR	9.04	8.53 (-5.64)	5.05	2.20 (-56.44)	46.20	17.85 (-61.89)
Gypsum at 25% SGR + FM at 10 t ha^{-1}	9.04	8.55 (-5.42)	5.05	2.00 (-60.40)	46.20	16.22 (-64.89)
Chiseling + Gypsum at 25% SGR	9.04	8.62 (-4.65)	5.05	2.32 (-54.06)	46.20	19.90 (-56.93)
Chiseling + Gypsum at 25% SGR+ FM at 10 t ha^{-1}	9.04	8.46 (-6.42)	5.05	1.95 (-61.39)	46.20	14.50 (-68.61)
Sulphur eq. to Gypsum at 50% SGR	9.04	8.54 (-5.53)	5.05	2.30 (-54.56)	46.20	18.80 (-59.31)

The values in parenthesis represent the percent decrease (-)/increase (+) in the respective soil properties

Table 2: Effect of different amelioration strategies on physical properties of soil after the harvest of fodder beet crop by the end of three years of experimentation

Treatments	Bulk density (Mg m^{-3})		Hydraulic conductivity (cm h^{-1})		Organic matter (%)	
	2009-2010	2011-2012	2009-2010	2011-2012	2009-2010	2011-2012
Control	1.69	1.63 (-3.55)	0.34	0.40 (+17.65)	0.47	0.53 (+12.77)
Gypsum at 100% SGR	1.69	1.26 (-25.44)	0.34	0.92 (+170.58)	0.47	0.69 (+46.81)
Gypsum at 50% SGR	1.69	1.38 (-18.34)	0.34	0.75 (+120.58)	0.47	0.57 (+21.28)
Gypsum at 25% SGR + FM at 10 t ha^{-1}	1.69	1.35 (-20.11)	0.34	0.86 (+152.94)	0.47	0.66 (+40.43)
Chiseling + Gypsum at 25% SGR	1.69	1.46 (-13.61)	0.34	0.71 (+108.82)	0.47	0.56 (+19.15)
Chiseling + Gypsum at 25% SGR+ FM at 10 t ha^{-1}	1.69	1.22 (-27.81)	0.34	0.97 (+185.29)	0.47	0.70 (+48.94)
Sulphur eq. to Gypsum at 50% SGR	1.69	1.49 (-11.83)	0.34	0.69 (+102.94)	0.47	0.58 (+23.40)

The values in parenthesis represent the percent decrease (-)/increase (+) in the respective soil properties

Table 3: Effect of different amelioration strategies on germination and root growth of fodder beet crop (Average of three years)

Treatments	Germination (%)	Root fresh weight (t ha^{-1})	Root dry weight (t ha^{-1})	Root length (cm)	Root diameter (cm)
Control	59.00 e	53.83 d	8.36 d	18.00 e	9.10 d
Gypsum at 100% SGR	85.00 a	70.0 a	17.47 a	32.00 ab	16.00 a
Gypsum at 50% SGR	71.66 c	59.86 c	11.53 bc	27.33 c	14.24 ab
Gypsum at 25% SGR + FM at 10 t ha^{-1}	76.00 b	64.55 b	12.60 b	28.00 bc	14.04 ab
Chiseling + Gypsum at 25% SGR	62.66 d	57.76 cd	10.66 b-d	22.33 d	11.00 cd
Chiseling + Gypsum at 25% SGR+ FM at 10 t ha^{-1}	86.00 a	69.03 a	17.42 a	33.00 a	15.20 a
Sulphur eq. to Gypsum at 50% SGR	65.33	58.30 c	9.55 cd	24.00 cd	12.18 bc
LSD at 5%	3.11	4.21	2.65	4.19	2.85

Means sharing the same small letters are statistically similar at $P \leq 0.05$; SGR = soil gypsum requirement

Table 4: Effect of different amelioration strategies on shoot growth and yield of fodder beet crop (Average of three years)

Treatments	Shoot fresh yield (t ha^{-1})	Shoot dry yield (t ha^{-1})	Shoot height (cm)	Number of leaves per plant
Control	9.60 e	1.40 d	40.00 d	15.33 d
Gypsum at 100% SGR	19.79 a	4.43 a	66.00 a	29.00 ab
Gypsum at 50% SGR	16.26 c	2.77 c	54.00 bc	23.00 c
Gypsum at 25% SGR + FM at 10 t ha^{-1}	17.18 bc	3.34 b	59.33 ab	25.00 bc
Chiseling + Gypsum at 25% SGR	12.63 d	1.87 d	50.00 c	17.00 d
Chiseling + Gypsum at 25% SGR+ FM at 10 t ha^{-1}	19.12 ab	4.03 a	64.33 a	29.33 a
Sulphur eq. to Gypsum at 50% SGR	15.79 c	2.50 c	56.00 bc	22.33 c
LSD at 5%	2.42	0.55	6.78	4.13

Means sharing the same small letters are statistically similar at $P \leq 0.05$; SGR = soil gypsum requirement

Table 5: Effect of different amelioration strategies on net income and benefit: cost ratio (BCR) of fodder beet crop (Total of three years)

Treatments	Cost of production (Rs. ha^{-1})	Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	Benefit: cost ratio (BCR)
Control	225100	411438	186338	1.83
Gypsum at 100% SGR	245900	512500	266600	2.08
Gypsum at 50% SGR	234500	449125	214625	1.92
Gypsum at 25% SGR + FM at 10 t ha^{-1}	239300	478438	239138	2.00
Chiseling + Gypsum at 25% SGR	235050	436000	200950	1.85
Chiseling + Gypsum at 25% SGR + FM at 10 t ha^{-1}	243050	506438	263388	2.08
Sulphur eq. to Gypsum at 50% SGR	260079	439375	179296	1.69

were recorded where chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1} was applied, but it was statistically at par where gypsum was applied at 100% SGR (Table 4). Minimum number of leaves per plant and shoot length was with the control treatment (Table 4). Maximum fresh (19.79 t ha^{-1}) and dry yield (4.43 t ha^{-1}) was recorded when gypsum was applied at 100% SGR, but it was statistically at par with chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1} (Table 4). The control treatment was the least effective for these growth parameters (Table 4).

Economic analysis indicated that different remedial strategies had significant effect on gross income, net income and benefit: cost ratio (BCR) of fodder beet grown under saline-sodic conditions (Table 5). Maximum gross income, net income and BCR were recorded where gypsum at 100% SGR and chiseling + gypsum at 25% SGR + FM at 10 t ha^{-1} were applied (Table 5). Minimum gross income, net income and BCR were recorded where Sulphur eq. to gypsum at 50% SGR were applied (Table 5).

Discussion

The results of studies elaborated that amendments notably improved the soil physical and chemical properties viz. bulk density, hydraulic conductivity, organic matter contents, pH_s, EC_e and SAR, and productivity of fodder beet (Tables 1-4).

Among the amendments used, the best amendment was chiseling + gypsum application at 25% of SGR + FM at 10 t ha^{-1} followed by the application of gypsum at 100% of SGR. These two amendments highly improved all aforementioned physical and chemical properties of saline-sodic soil. Leaching of Na^+ ions from root zone in result of applied amendments might be the major reason of reduced pH_s, EC_e and SAR. The sharp decline in soil pH_s was due to release of Ca^{2+} from gypsum, which replaces the exchangeable Na^+ (Abdel-Fattah, 2012). However, deep tillage, chiseling in particular, is often helpful in lowering the soil penetration resistance, bulk density and hydraulic conductivity, and improving infiltration rate of salt-affected soils (Daniel *et al*., 2005). Improvement in hydraulic conductivity is possible with simulated sub soiling and gypsum-saturated solution (Shahid, 1993). Addition of organic matter in the form of FM might provide a buffer to soil solution (McCormick and Wolf, 1980); as FM drastically enhanced soil organic matter with a subsequent decrease in pH_s of plots receiving the integrated treatments could be related to release of organic acids and CO_2 during the decomposition of FM (Tisdale *et al*., 1985). Similarly, adding organic matter to the soil improves chelation ability of Ca^{2+} and Mg^{2+} in soil solution to replace Na^+ from the cation exchange complex, mostly at alkaline pH_s values, leading to decline in SAR (Gaffar *et al*., 1992; Qadir and Oster, 2002).

Three years pooled data elaborated substantial expansion in roots traits viz. root length and diameter, and root fresh and dry weight with gypsum application at 100% of SGR and chiseling + gypsum application at 25% of SGR + FM at 10 t ha^{-1} (Table 3); due to notable improvement in soil physical and chemical properties like bulk density, hydraulic conductivity, pH_s, EC_e, SAR and organic matter contents of soil (Tables 1-2). Moreover, salt-affected soils are generally poor in nutrients; hence organic matter addition in such soils supplements the rhizosphere with essential plant nutrients and counteracts nutrient depletion (Lakhdar *et al*., 2008). So positive effects of FM by improving the supply of nutrients after its decomposition might be responsible of improved root growth leading to highest root fresh and dry weight in the plots where FM was applied along with chiseling and gypsum. The ameliorating effects of gypsum and FM tied with chiseling might be responsible for reclamation of saline-sodic soils (Lakhdar *et al*., 2008; Mohamed *et al*., 2012) leading to higher production of fresh and dry yield of fodder beet in these treatments. Crop might also benefited by the improved physical properties of soil including increased soil porosity and aggregation, reduced bulk density, hydraulic conductivity, increased soil aeration, low soil temperature and reduced resistance to root penetration due to application of FM and gypsum along with chiseling (Hussain *et al*., 2001; Tzanakakis *et al*., 2011; Mohamed *et al*., 2012).

However, the substantial improvement in soil physical and chemical properties i.e., bulk density, hydraulic conductivity, organic matter, pH_s, EC_e and SAR by growing fodder beet without any amendment (control) highlighted the potential of fodder beet to be used as biological amendment to reclaim saline-sodic soil; as the replaced Na^+ is either leached from root zone by excess irrigation, and/or taken up by crops (Qadir and Oster, 2002). Moreover, the importance of fodder beet as a biological amendment to reclaim saline-sodic soil was also linked with its ability to supply fodder for the livestock.

Economic viability in monetary terms of any innovation or technique has prime importance in determining its wider adoption among farming community (Khan *et al*., 2012). The findings of this three years field study disclosed that soil amendments with the application of gypsum at 100% of SGR and chiseling + gypsum application at 25% of SGR + FM at 10 t ha^{-1} were the more economical due to elevated net income and benefit: cost ratio (BCR) compared with all other amendments used (Table 5). Soil amendment with sulphur seemed the least profitable even than the control (growing fodder beet without any amendment). Moreover, BCR of 1.83 by growing fodder beet without any other amendment highlighted its potential to be used as organic amendment to reclaim saline-sodic soils (Table 5).

Conclusion

Application of gypsum alone or with FM is normally practiced in Pakistan to improve productivity of salt affected soils. The integrated application of FM and gypsum even at 25% of SGR combined with chiseling proved highly beneficial in improving chemical and physical soil properties. Moreover, due to improvement in soil physical and chemical properties tied with BCR of 1.83, cultivation of salt tolerant species like fodder beet highlighted its potential to be used as organic amendment to reclaim saline-sodic soils. Therefore, based on results of this three-year field trial, combined application of gypsum and FM with chisel plough is recommended as an effective method for the amelioration of calcareous salt affected soils and enhancing the productivity of fodder beet in saline-sodic soil.

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