REHABILITATION OF PROBLEM SOILS THROUGH ENVIRONMENTAL FRIENDLY TECHNOLOGIES - II: ROLE OF SESBANIA *(SESBANIA ACULEATA)* AND GYPSUM

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Abstract

The effect of sesbania green manure and gypsum application (0, 50, 75 and 100 percent of gypsum requirement) on rice was investigated in a field study on a sodic soil at the Saline Agriculture Research Station, Sadhuke, Lahore, Pakistan. Sesbania was grown for two months and then incorporated into the soil as green manure. Gypsum was applied before the sowing of sesbania. Basmati 385 was used as the test variety of rice.

Sesbania green manuring significantly increased the number of productive rice tillers. Although paddy and straw yields were also increased (13.1 and 14.2 percent respectively), the differences were statistically not significant. Productive tillers, paddy and straw yield were significantly increased by gypsum application. Differences in paddy yield due to 75 and 100 percent gypsum application rate were not significant indicating that gypsum applied at low rates was just as effective as high rates. Green manuring significantly increased N utilization by both grain and straw but did not impact P uptake. The application of gypsum significantly increased the N and P uptake; the differences between 100 and 75 percent gypsum requirement (GR) treatments were not significant, but were significantly higher than the 50 percent gypsum requirement (GR) rate.

Key words: Reclamation, Environmental friendly, Agroforestry, Gypsum and Salinity, *Sesbania aculeata*

INTRODUCTION

To meet the food, fiber and fuel demands of a growing population, tremendous pressure is being put on the presently available land resources. Of the world's cultivated lands, more than 7 percent (1.5×10^9ha) are sufficiently affected by salts to reduce the agronomic potential of these areas (Mudie, 1974). Considerable progress has been made in the past few decades in reclamation of some of these soils. Unfortunately, about 3 percent of the world's land surface (2.3×10^8 ha) is dominantly saline, saline-sodic, or sodic soils (Dudal and Purnell, 1986). In Pakistan, land degradation resulting from soil salinity, sodicity or a combination of both is a major impediment to economic utilization of land resources under arid and semiarid climatic conditions (Ahmad et al., 1990). There are several practical methods for reclaiming these salt-affected soils. However, the usefulness of each method depends on several considerations.

Saline soils are usually reclaimed by ponding water on the soil and removing the leached salts to a sink (drainage or groundwater). But reclaiming saline-sodic soils requires removal of sodium (Na^{+1}) from the soil's cation exchange sites, usually by treatment with calcium (Ca^{2+}), and leaching of the replaced Na^{+1} out of the root zone by percolation (Ghafoor, 1984; Ahmad et al., 1990). Because of its low cost, general availability, and rich supply of Ca^{2+}, gypsum is the most extensively used agent in reclamation of saline-sodic soils (Oster, 1982; Ghafoor, 1984; Bajwa and Josan, 1989).

Although many sodic and saline-sodic soils of Pakistan contain lime ($CaCO_3$) at varying depths (Choudhry, 1972), this source of calcium generally remains ineffective in soil exchange reactions with Na^{+1} due to its negligible solubility. Chemical amendments can attack the problem in two ways. First, gypsum or calcium chloride applications supply soluble calcium directly (Oster, 1982; Frenkel et al., 1989; Ghafoor et al., 1990; Arora and Singh, 1981). Second, the native insoluble calcium can be solubilized by addition of calcium, sulfuric, hydrochloric, or nitric acid (Ghafoor and Mohammed, 1981; Ahmad et al., 1986), sulphur (Chaudhry et al., 1982), or iron and aluminum sulphates (Chand et al., 1977). Application of these amendments followed by leaching can ameliorate saline-sodic soils. However, the initial cost of these amendments restricts their potential use, especially by farmers with limited funds (Ahmad et al., 1990; Bajwa et al., 1991).

The application of gypsum will increase soil porosity and reduce surface crusting (Chartres et al., 1985; Greene et al., 1988; Southard et al., 1988). Gypsum can also increase soil permeability (Chartres et al., 1985; Hussain et al., 1988; Frenkel et al., 1989) and improve the chemical properties of saline-sodic soils (Bajwa and Josan, 1989; Carter and Pearson, 1989). However, most of these effects are limited to shallow depths.

The cation exchange between Ca and exchangeable Na^+ can take place only in solution. In fine-textured soils, the slow infiltration and flow of water in the soil slows the exchange process. Mixing of gypsum throughout the soil layer speeds the exchange process (Oster, 1982;

Frenkel et al., 1989). If the soil profile permeability is low or a water-restricting layer exists, mixing of gypsum will not be effective unless sodium is removed laterally.

To monitor leaching effectiveness during the reclamation process, soil samples can be taken periodically and analyzed. Also, salt-sensors can be used to monitor salt movements in the profile (Hoffman, 1981), but are not useful in describing soil chemical properties, such as sodium adsorption ratio (SAR) and pH. Many previous studies involved with reclamation of saline-sodic soils have been done in laboratories with closely defined physio-chemical properties, mostly of the surface soil layer. Only limited field data are available on downward removal of excess sodium. This latter aspect is addressed in the current field study.

Water flow in soils occurs mostly in macro pores that are > 1 mm in diameter (Bouma et al., 1977; Germann and Beven, 1981; Meek et al., 1989). Fine-textured soils have more total pore space but have fewer macro pores than do coarse-textured soils. The salts held in micro pores remain largely immobile under steady-state conditions, because micro pores take little part in water flow (Gish and Jury, 1983). One economical way to increase the proportion of macro pores in the soil profile is through growing of deep-rooted crops, such as alfalfa *(Medicago sativa)* and bahiagrass (*Pospalum notatum*) (Charles and Sickle, 1984; Angers and Mehuys, 1988; Meek et al., 1990). Unfortunately, alfalfa does not have high tolerance of salts (Ilyas, 1990). Among the salt-tolerant plants, sesbania (*Sesbania aculeata*) can successfully colonize problem soils. Sesbania is considered an integral component of agro forestry systems and is an effective element in reclamation strategies if used as green manure (Evans and Rotar, 1987; Ahmed, 1991; Baig et al. 2005 a; Baig et al. 2005 b).

Plants can also change the chemical properties of saline-sodic soils (Ahmad et al., 1990; Ahmed, 1991). These changes occur during the release of organic carbon and exudates (Dormaar, 1988; Treeby et al., 1989). Changes in soil pH (Liu et al., 1989; Youssef and Chino, 1989), the addition of organic matter and nutrients (Lal et al., 1979; Yamoah et al., 1986), and the increased dissolution of lime in presence of CO_2 evolved from decomposition of organic matter and plant root respiration (Gupta and Karan, 1985; Gupta et al., 1988) are additional soil alterations.

Only a limited amount of work demonstrates that crops can change the chemical properties of saline-sodic soils during reclamation. The effects of chemical amendments like gypsum and the deep-rooted crops like sesbania alone or in combination for reclamation of saline-sodic soils have not been widely studied, particularly in Pakistan. The present study focuses on an effort to rehabilitate salt- affected soils through biological and chemical means, and to devise an appropriate and economical technology for increasing yields from these problem lands.

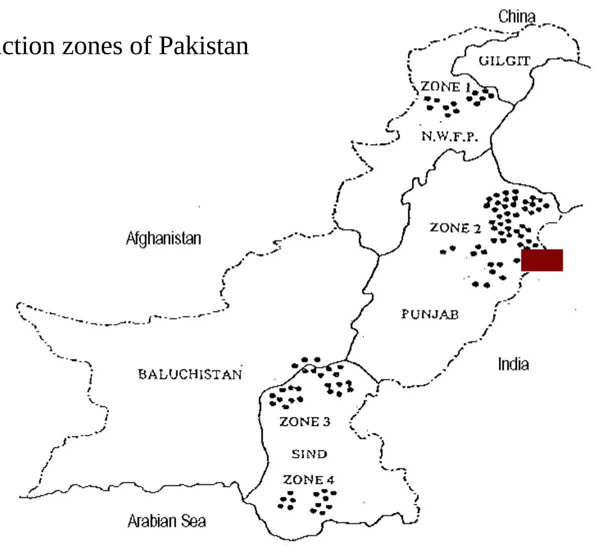
In this experiment, the cumulative effects of gypsum application and sesbania green manure on rice production on a saline-sodic soil under a rice-wheat rotation were investigated.

MATERIALS AND METHOHDS

The Study Site

The study was conducted on the Saline Agriculture Research Station, Sadhuke, Punjab, Pakistan, located 30 kilometers north of Lahore. The arid and continental climates are characterized by hot and dry summers, maximum temperature 41^{o}C, and cold winters with temperatures dropping to 12.2^{o}C. The mean annual rainfall ranges between 325 and 755 mm, of which 75 percent is received during the monsoon months (July - September). The rainfall is less than potential evapotranspiration (Map 1).

Map 1. : Major rice production zones of Pakistan



Chemical Composition of the Experimental Soil

The soils of the experimental site belong to the major group of alluvium of the Indus Plain, characterized as fine loamy, mixed, thermic, Typic Natrustalf. Soil characterization was done before the start of the experiment. Results of a chemical analysis of soils from the experimental site are shown in Table 1. The soil is alkaline, calcareous and saline-sodic in nature. It is extremely deficient in nitrogen and organic matter. Potassium and micronutrients are sufficiently present in the soil.

Experimental Design and Treatments

The study was organized in a completely randomized block design using three replications of the following treatments:

- T1 No green manure & no gypsum application (control).
- T2 No green manure + gypsum application @ 50 % of gypsum requirement (GR).
- T3 No green manure + gypsum application @ 75 % of GR.
- T4 No green manure + gypsum application @ 100% of GR.
- T5 Green manuring with sesbania & no gypsum application.
- T6 Green manuring with sesbania + gypsum application @ 50 % of GR.
- T7 Green manuring with sesbania + gypsum application @ 75 % of GR.
- T8 Green manuring with sesbania + gypsum application @ 100 % of GR.

Sesbania was grown for two months and then incorporated as green manure into the soil with a rotavator. The gypsum requirement (GR) was determined by Schoonover's method described by U. S. Salinity Lab (1954) in Hand Book 60. Calcium+Magnesium were determined by titration with standard versinate solution and Na^{+1} flame photometrically, to calculate sodium adsorption ratio (SAR), following the procedures, outlined by U. S. Salinity Lab. Staff (1954). Agricultural grade gypsum powder (passed through a 70 mesh sieve and having 90% purity) was applied before the sowing of sesbania to ensure better growth of the green manuring crop. Rice (variety Basmati 385) was transplanted after the incorporation of sesbania and grown to maturity. Nitrogen and phosphorus were applied at the rates of 80 and 50 kg/ha, respectively. Two thirds of the N and all of the P were applied as basal doses before sesbania was planted. The remaining N was applied at panicle initiation. Data on number of productive tillers, and on paddy and straw yields were recorded at the time of rice harvesting. Plants were chemically analyzed for N and P in the laboratories of the Land Resources Research Institute at National Agricultural Research Center, Islamabad, Pakistan, following procedures described by Prevel et al. (1987). Nitrogen and phosphorus uptake in straw and grain were determined by multiplying the concentration of the element by its respective yield.

Statistical Analysis

Data were analyzed statistically by using analysis of variance (ANOVA) based on completely randomized block (CRB) design. Treatment differences were determined using Duncan's Multiple Range Test (DMRT) (Duncan, 1955). The SAS program (SAS Institute, 1985) was used to analyze the data and to compare means at 0.05 alpha level.

RESULTS AND DISCUSSION

Effect of Sesbania and Gypsum on Rice Yield

Sesbania green manuring significantly increased the paddy and straw yields by 13.1 and 14.2 percent, respectively (Table 2). Sesbania green manuring also significantly increased the number of productive tillers. Dargan et al. (1975) in an alkali (sodic) field experiment with sesbania found that with no addition of fertilizer N, incorporation of a 65-days-old sesbania crop as green manure increased yields of rice from 2.64 t/ha to 5.64 t/ha. Similarly, Khind et al., (1987) reported that sesbania helped in reclamation of sodic soil by lowering the adverse effects of Na, which helped improve soil physical conditions leading to better crop productivity. Unlike chemical fertilizers, there is also a relatively prolonged (one to three weeks) availability of N from sesbania to crops (Bhardwaj and Dev, 1985). These factors may have caused increased yields in this study.

Gypsum application significantly increased productive tillers, straw and paddy yields (Table 2). However, the differences in paddy and straw yield between treatments of 100 and 75 percent of gypsum requirement were not significant. Ahmad et al. (1990) evaluated sesbania, gypsum and other reclaments on a saline-sodic field. They reported that sesbania and gypsum produced grain yields of 3788 kg/ha and 3677 kg/ha, respectively, which were higher than other treatments. Puddling and flooding is also known to reduce the harmful effects of sodicity and lower pH. These existing soil conditions have probably contributed the beneficial effects of gypsum and may have produced the non-significant differences between the gypsum level treatments of 75 percent and 100 percent of GR requirement.

Effect of Sesbania and Gypsum on Nitrogen Concentration in Rice

A significant effect of green manuring and gypsum application on N concentration in rice grain and straw was recorded (Table 3). The greatest increases in N concentration, however, were in observed in areas receiving GM and gypsum at the rate of 100 percent gypsum requirement. Although Singh et al. (1988) observed losses of N from sesbania green manure under flooded and waterlogged conditions and ultimate low N concentrations, similar effects did not occur here.

Effect of Sesbania and Gypsum on Nitrogen Uptake in Rice

Nitrogen uptake in grain, straw and grain+straw was significantly increased with sesbania green manuring (Table 4). The process of puddling in transplanted rice probably allows for more and thorough incorporation of green manure in the soil. The significant increase in N uptake in rice could be attributed to continuous, prolonged and greater accumulation of N in the soil. Similar results have been reported by Panda et al. (1991) under different climatic and soil conditions.

Nitrogen uptake in grain and straw was also significantly increased with the application of gypsum (Table 4). The highest uptake resulted from the 100 percent GR treatment. However, the differences between 50 and 75 percent gypsum requirement (GR) were greater than differences between 75 and 100 percent. It is obvious from the data that application of lower levels of gypsum requirement resulted in much less Na replacement from the exchange complex than at the higher levels.

Effect of Sesbania and Gypsum on Phosphorus Concentration in Rice

There was no significant effect of green manuring on P concentration in rice grain and straw (Table 5). This non-significant effect due to addition of green manuring may be because alkaline calcareous soils in general (Chhabra et al., 1981) and rice soils in particular already contain high amounts of available P (Zia, 1990). Phosphorus concentration in rice grain was significantly enhanced due to gypsum application at the 75 percent and 100 percent GR levels (Table 5). There were, however, no significant differences in P concentration in both grain and in straw between control and 50 percent GR application and between the 75 and 100 GR levels. Gupta et al. (1988) have shown that level of electrolyte, sodium saturation, pH, and the presence of alkalinity causing anionic species together or in combination enhance release of P from calcareous sodic soils. The data suggest that non-significant differences among the treatments may result from an increase in soluble P due to flooding. The statistically significant difference between control and the highest levels of gypsum requirement clearly demonstrates the usefulness of gypsum in increasing P concentration in rice.

Effect of Sesbania and Gypsum on Phosphorus Uptake in Rice

Phosphorus uptake in both rice grain and straw was significantly affected by sesbania (Table 6). Meelu et al. (1991) reported increased utilization of P from the soil supplies by the crop due to sesbania application; perhaps more utilization from the reserve sources may be due to sesbania decomposition. Gypsum application significantly increased the P uptake in grain, straw, grain+straw at all levels of application. However, the increase at the 50 percent gypsum requirement (GR) level was not as great as at 75 and 100 percent levels. Differences between the 75 and 100 percent of gypsum requirement (GR) treatment were not significant (Table 6). In several field studies, gypsum improved the chemical properties of saline-sodic soils by lowering exchangeable sodium, reducing electrical conductivity, and lowering pH of the root zone (Chauhan and Tripathi, 1983; Hussain et al., 1988; Bajwa and Josan, 1989; Carter and Pearson, 1989; Ahmad et al., 1990).

However, the effectiveness of the amendment appears to be dependent on the amount of gypsum added, and the amount and chemical composition of irrigation water applied (Oster, 1982; Hoffman, 1986). Low response among the treatments can be attributed to the difference in rates of gypsum applied and the use of brackish irrigation water in this study. The data show that gypsum could not completely offset the deleterious effects of Na when used at 50 percent GR. The findings are in agreement with those of several workers (Ghafoor, 1984; Ghafoor et al., 1990; Ahmad et al., 1990).

CONCLUSIONS AND RECOMMENDATIONS

Based on the results obtained in this study the following conclusions are drawn:

1. The study shows that sesbania green manuring significantly improves problem soils in Punjab by ameliorating the physical and chemical properties of the soil. These properties also improve N and P nutrition of the following rice crop.
2. Sesbania and rice crops help to balance nutrient supply, protect leaching and act as a buffer against salinity/sodicity by lowering pH.
3. Maximum increases in paddy (75 percent) and straw yield (66 percent) were obtained when gypsum was applied at the 75 and 100 percent GR rate.
4. Gypsum significantly enhanced N and P uptake. However, N and P utilization were significantly lower at the 50 percent GR application compared to higher rates. Therefore, higher rates of gypsum application seem appropriate and are recommended, based on detailed soil analyses to determine the needed amendments.
5. To propagate the amendment idea among common farmers, the economic and biologic factors need to be analyzed. Farmers with the poor resources would adopt the practices having less initial cost but more net returns in a short rather than long term.
6. The combination of sesbania green manure and gypsum at moderate levels physically and chemically improve problem soils, achieve sustainability, and improve optimum net returns in the long run.

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Tab. 1. : Chemical analysis of the soil used in the amendment study

Parameter	Surface soil (0-15 cm)	Sub soil (15-30 cm)
pH	8.4	8.8
ECe (dS m^{-1})	8.5	7.8
SAR	49.5	40.5
OM (%)	0.65	0.51
$CaCO_3$ (%)	0.80	1.30
Ca (%)	0.22	0.20
Total-N (%)	0.07	0.07
NH_4-N(mg/kg)	5.33	7.03
NO_3-N(mg/kg)	0.59	0.46
P (mg/kg)	6.06	5.96
K (mg/kg)	190.00	170.00
Fe (mg/kg)	22.70	17.89
Cu (mg/kg)	2.69	2.33
Mn (mg/kg)	2.10	1.17
Zn (mg/kg)	1.17	1.20

Tab. 2. : Effect of sesbania and gypsum application on rice yield

Gypsum level	Productive tiller/plant			Paddy yield (t/ha)			Straw yield (t/ha)		
	No GM	**GM**	**Mean**	**No GM**	**GM**	**Mean**	**No GM**	**GM**	**Mean**
0	0.07	10.07	9.07d	1.76	2.30	2.03c	2.26	3.00	2 .63c
50	9.47	10.87	10.17c	2.46	2.71	2 .58b	3.09	3.30	3.20b
75	9 .67	12.53	11.10b	3.06	3.38	3.22a	3 .54	4 13	3.83a
100	9.80	13.13	11.49a	3.08	3.34	3.23 a	3.75	4.00	3.87a
Means for GM	**9.25b**	**11.66a**		**2.59b**	**2.94a**		**3.16b**	**3.61a**	

* Means sharing the same letter are statistically not different at p 0.05
** No GM = Sesbania was not added
*** GM = Sesbania was added

Tab. 3. : Effect of sesbania and gypsum on nitrogen concentration in rice

Gypsum level	N concentration in grain (%)			N concentration in straw (%)		
	No GM	GM	Mean	No GM	GM	Mean
0	0.957	0.96	0.958c	0.383	0.413	0.398c
50	0.91	1.043	0.977c	0.453	0.467	0.460b
75	0.993	1.073	1.033b	0.453	0.487	0.470b
100	0.97	1.887	1.429a	0.47	0.533	0.502a
Means for GM	**0.958b**	**1.241a**		**0.440b**	**0.475a**	

* Means sharing the same letter are statistically not different at p 0.05
** No GM = Sesbania was not added
*** GM = Sesbania was added

Tab. 4. : Effect of sesbania and gypsum application on nitrogen uptake by rice

Gypsum level	N uptake by grain (kg/ha)			N uptake by straw (kg/ha)			Total uptake by grain +straw (kg/ha)		
	No GM	GM	Mean	No GM	GM	Mean	No GM	GM	Mean
0	16.79	21.91	19.35d	9.06	12.4	10.73d	25.85	34.31	30.08c
50	22.32	28.46	25.39c	13.99	15.25	14.62c	36.32	43.71	40.18b
75	30.34	32.83	31.58b	16.75	20.08	18.42b	47.1	56.24	51.00a
100	29.52	36.17	32.84a	17.62	21.36	19.47a	47.44	57.53	51.32a
Means for GM	**24.74b**	**29.84a**		**14.36b**	**17.27a**		**38.68b**	**47.11a**	

* Means sharing the same letter are statistically not different at p 0.05
** No GM = Sesbania was not added
*** GM = Sesbania was added

Tab. 5. : Effect of sesbania and gypsum application on phosphorus concentration in rice

Gypsum level	P concentration in grain (%)			P concentration in straw (%)		
	No GM	GM	Mean	No GM	GM	Mean
0	0.29	0.297	0.295b	0.157	0.147	0.152ab
50	0.30	0.3	0.300b	0.147	0.147	0.147b
75	0.35	0.342	0.344a	0.16	0.163	0.162a
100	0.35	0.34	0.346a	0.153	0.163	0.158a
Means for GM	**0.323a**	**0.320a**		**0.154a**	**0.155a**	

* Means sharing the same letter are statistically not different at p 0.05
** No GM = Sesbania was not added
*** GM = Sesbania was added