DEVELOPMENT OF SITE SPECIFIC MANAGEMENT FOR RECLAMATION OF SALT AFFECTED SOIL ULITLIZALING PRELIMINARY EM-38 AND CORE SOIL SAMPLE DATA

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Abstract

Salinization is one of the most serious problems confronting sustainable agriculture in any irrigated production system in a semi-arid or arid region. Salts are imported in irrigation water and tend to be left in the soil due to the deficit between rain and evapotranspiration deficit present in semi-arid and arid environments. Poor drainage and a high water table exacerbate the problem. A considerable portion of the West Side of the San Joaquin Valley is or has the potential to become salt-affected. In general, salinity and sodicity are not uniformly distributed in a field but rather are very patchy. The objective of this preliminary study is to determine the initial steps needed in the development of methodology to be used for site-specific reclamation of salt-affected soils. When fully developed the method will work as follows: preliminary measurements of bulk soil electrical conductivity, remotely sensed images, and yield map data will be integrated to develop directed sampling plans for extraction of soil cores to measure soil chemical, physical, and drainage properties. These measurements, together with the preliminary data, will then be used to interpolate soil properties over the field. An optimization scheme will then be used to determine the most appropriate combination of amendments and irrigation, and the spatial distribution of amendments, based on the type and configuration of the fields irrigation system. A system of replicated trials in commercial fields will be used to develop the statistical relationships necessary for the study.

Introduction

Fully irrigated, Mediterranean climate or desert agricultural systems, such as are found in California and the Southwest, are among the most productive in the world. Clear skies during most of the summer ensure that high-value summer crops will receive substantial solar radiation, and the lack of rainfall during this period ensures that the grower has a relatively high level of control over the crop environment through irrigation. However, such irrigated systems are also among the most difficult to sustain over a long period. A major problem with such production systems is the gradual accumulation of soil salinity. Although some salinity is inherently present in the soil, the primary cause of salinization is the importation of salts in irrigation water. In arid and semi-arid areas where rainfall is insufficient to leach salts from the soil, this salt will gradually accumulate (Richards, 1954). Approximately 4.5 million acres of irrigated cropland in California, primarily on the west side of the San Joaquin Valley, are affected by saline soils or irrigation water (Letey, 2000).

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Managing soil salinity involves several aspects, of which two of the most important are disposing of saline drainage water and reclaiming fields whose productivity is limited by salinity. This second problem of land reclamation is the component addressed in this study. Crop response to the osmotic and toxic effects of soil salinity varies by species. Tolerance also depends on the time of the season. Cotton is relatively sensitive to salinity at emergence due to effects on the soil structure, but is less sensitive once the plant is established (Hake et al, 1996).

The most appropriate reclamation procedure depends on the nature of the ionic chemistry affecting the soil. Salt affected soils are traditionally divided into three broad categories depending on the extent to which they are saline or sodic (also called alkali) (Richards, 1954). Saline soils are those for which the electrical conductivity of the saturation paste extract, denoted EC_e, is greater than 4 dS/m and whose exchangeable sodium percentage (ESP) is less than 15% (Richards, 1954). Establishing adequate drainage and providing adequate low sodium water to leach the salts from the system may reclaim such soils. Saline-sodic soils are those with an EC_e of at least 4 dS/m and an ESP of at least 15%. Application of low ionic concentration water to leach saline-sodic soils removes the excess salts, giving the soil the characteristics of sodic soils. These are soils with an ESP greater than 15% and an EC_e less than 4 dS/m. such soils are highly alkaline. The relatively lesser attraction of the sodium ion to clay particles causes these soils to swell and disperse, leading to reduction in water infiltration rate (Richards, 1954).

Saline-sodic and sodic soils, that is, soils with an excess of exchangeable sodium, may be reclaimed by the application of appropriate amendments together with adequate water (Richards, 1954). The desired effect of the amendments is a cation exchange of calcium for sodium so that low sodium water can be used to leach the exchanged sodium. Therefore the amendments must supply calcium, either directly or indirectly. The most effective and economic means of doing this depends on the soil chemistry. If the soil is low in carbonate, then the calcium must be supplied directly. The most common amendment in this condition is gypsum, although in some cases (generally those of low pH), lime may also be used. If the soil has sufficient calcium carbonate, then this may be used as a source of the calcium. In this case, sulfuric acid may be applied. It reacts with calcium carbonate to form gypsum, which then supplies exchangeable calcium. Alternatively, sulfur may be applied. This forms sulfuric acid in the soil through microbial actions, and the sulfuric acid in turn reacts to form gypsum. Because of the need to remove salts through leaching, the salinity properties of the soil and the nature of the reclamation are highly affected by the field drainage and water table.

One of the primary impediments to the reclamation of saline-sodic soil is its high cost. This problem is exacerbated by the fact that many large fields show considerable spatial variability in their salinity condition, so that the appropriate reclamation procedure for one part of a field may be ineffective or even harmful to another part, and in many cases only a portion of the field needs reclamation at all.

This tendency of saline and sodic conditions to occur in patches makes soil reclamation and ideal practice on which to apply site-specific management (SSM). Site-specific management, also called precision agriculture, is the management of an agricultural crop at a spatial scale smaller than that of the individual field (Plant et al., 2000b). The principle behind SSM is that in many fields the crop's environment varies substantially from one part of the field to another. By adjusting management practices and input levels according to what is appropriate for local conditions the farmer can in principle save money, improve yield, and reduce unwanted environmental effects.

Materials and Methods

Preliminary EM-38 horizontal and vertical survey readings were georegistered and collected on two commercial cotton fields located in the San Joaquin Valley, one site in 1999 (J&J Farms) near Mendota and the other site in 2000 (Sheely Farms) near Lemoore. The preliminary EM-38 readings taken in 1999 were from 32 locations within the J&J field. The ESAP-RSSD program (Lesch et al., 1995) was used to process the EM–38 survey data and generate the soil sampling plans. Sixteen (16) optimal sampling locations were identified for this field. Soil samples were collected from each site at 0-1, 1-2, 2-3, 3-4 feet. An NDVI analysis (Plant et al., 2000a) was also performed on this field, which at the time had a cotton variety trial. Both EM-38 and remote sensing technology were used in this field to locate the soil amendment trial area, which had high salinity and low yields, as compared to the rest of the field. This field also has drainage tiles, which could influence the results. The experiment for this field was laid out as a randomized complete block with four blocks and six treatments. Each plot consisted of 8 rows on a 30" bed. The treatments consisted of three soil amendments (13 tons of Gypsum @ 70%, 2 tons of Sulfur, Sulfuric acid) and two irrigation systems (furrow, sprinkler). The Sulfuric acid treatment because of delivery problems was not applied and the plots were therefore used as a second control.

The preliminary EM-38 readings taken in 2000 were from 192 location within Sheely's field. The ESAP-RSSD program (Lesch et al., 1995) was used to process the EM–38 survey data and generate the soil sampling plans. Twelve (12) optimal sampling locations were identified for this field. Soil samples were collected from each site at 0-1, 1-2, 2-3 feet. A commercial laboratory then analyzed both sets of soil samples for EC_e Ca^{++}, Mg^{++}, Na^+ SAR, and B from a saturation paste extract. The saturation percentage and gravimetric soil water content were also determined.

Data from both sites were used to calculate the ESP (exchangeable sodium percentage) and the amount of exchangeable sodium needed to be replaced in order to achieve a SAR of 5 for the top foot of soil according to the formulas.

1) $$\text{SAR} = \text{meq Na}^+ \Big/ \sqrt{\text{meq Ca}^{++} + \text{meq Mg}^{++} / 2}$$

where meq of Na^+, Ca^{++}, Mg^{++}, are determined from the saturation paste extract.

2) meq of Na^+ to be replaced

$$\text{meq Na}^+_{(r)} = X * \sqrt{\text{meq Ca}^{++} + \text{meq Mg}^{++} / 2}$$

meq $Na^+_{(r)}$ = meq of Na^+ to be replaced
X = SAR (desired SAR Value)

3) meq of Na^+ to be exchanged

meq $Na^+_{(e)}$ = (meq $Na^+_{(d)}$ – meq $Na^+_{(r)}$)
meq $Na^+_{(e)}$ = meq of Na^+ to be exchanged
meq $Na^+_{(r)}$ = meq of Na^+ to be replaced
meq $Na^+_{(d)}$ = meq of Na^+ determined by saturation paste extract

The amount of exchangeable sodium needed was then converted into the amount of soil amendment needed based on the USDA handbook # 60 (Richards, 1954):

meq $Na^+_{(e)}$ * 0.9 for Gypsum
meq $Na^+_{(e)}$ * 0.49 for Sulfuric Acid
meq $Na^+_{(e)}$ * 0.16 for Sulfur

This data was imported into Arcview and maps were generated showing the amount of amendment required at each location to achieve an SAR or 5.

Results

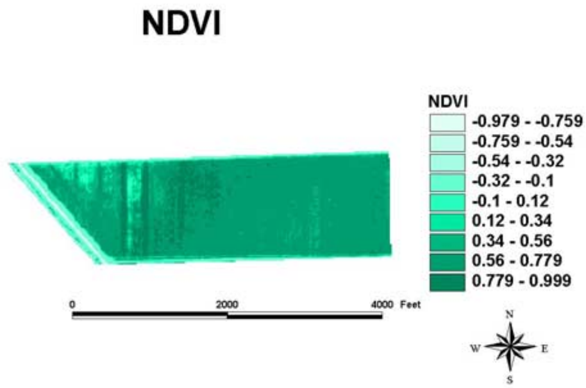

Figure 1. NDVI map of the full field used in the 2000 salinity experiment. The experiment was carried out on the west end of the field in the region marked with an arow (rows run north-south). The straight areas with high NDVI lie above drain tiles.

Figure 1 shows the NDVI for the full extent of the J&J field. The location of drain tiles can be seen clearly on the map. Table 1 gives the seed yield values for each of the plots in the 2000 experiment (F= furrow irrigation, S= sprinkler irrigation).

Table 1. Plot data for irrigation and amendment trial.

	Controls F	Controls S	Gypsum F	Gypsum S	Sulfur F	Sulfur S
	1375	2892	1750	3892	1428	3017
	1160	3231	1232	1482	1214	2017
	2303	1464	1839	2999	1714	2856
	1196	1553	2392	2089	1625	1767
	2803	2089				
	3446	2839				
	1892	1642				
	1732	2357				
ave	1988.38	2258.38	1803.25	2615.50	1495.25	2414.25
Stdev	815.26	679.45	475.07	1054.98	222.34	615.14

A split plot ANOVA was performed on the initial results (seed weight) for the J&J site. There was no significant yield response between the controls of the two types of irrigation (p>0.05) with and without the inclusions of the sulfuric acid treatment plots. There also was no significant yield response for each treatments compared to the controls and each irrigation system (p>0.05), although the difference between main plot treatments (sprinkler vs. furrow) almost reached significance (p=0.073).

Examination of Table 1 indicates a very high level of variability, which may mask some differences in treatments. Much of this variability may be due to the presence of the drain tiles in the experimental area. A comparison of the NDVI image of Fig. 1 with the locations of the experimental plots indicates that the higher yielding plots tend to be associated with drainage tile. Table .2 shows that the plots with lower sodium needing to be replaced tend to have higher seed weight yields. The tiles seem to be influencing about 100-foot wide band, primarily at the south end of the field, as seen in Fig.1.

Table 2. Relationship between Na^+ needing to be replaced and seed yield.

Treatment Id	Sample depth	Na^+ needed to replace	Seed wt yield	Irrigation System
101A	0-6"	11.40	1375.0	F
101B	0-6"	4.80	1375.0	F
105A	0-6"	15.38	2892.0	S
105B	0-6"	2.17	2892.0	S
105C	0-6"	1.65	2892.0	S
203A	0-6"	13.81	1196.0	F
203B	0-6"	10.23	1196.0	F
203C	0-6"	12.51	1196.0	F
207A	0-6"	2.20	1553.0	S
207B	0-6"	8.12	1553.0	S
303A	0-6"	-2.52	2803.0	F
303B	0-6"	5.01	2803.0	F
307A	0-6"	-1.45	2089.0	S
307B	0-6"	-3.30	2089.0	S
404A	0-6”	22.46	1732.0	F
404B	0-6"	1.58	1732.0	F
408A	0-6"	-5.04	2357.0	S
408B	0-6"	1.30	2357.0	S

We used equations (1) through (3) to compute the gypsum requirement for the area of the experimental plot. Fig. 2 shows an interpolation of the the results of this computation. The negative values may be interpreted as areas for which no gypsum is needed. It is evident that the primary need for amendment is in the north of the experimental area. Irrigation in this field is from south to north, and in addition a drainage canal runs along the western edge of the field (Fig. 1). It is likely that seepage from this canal is the primary cause of salinization in the field.

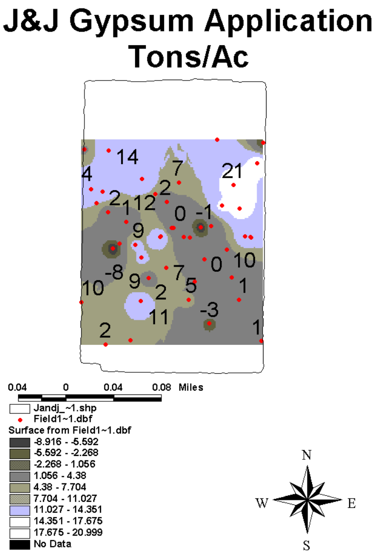

Figure 2. Estimated gypsum requirement in the experimental area of the J&J field.

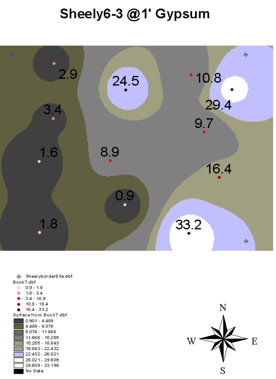

Figure 3. Calculated tons of gypsum necessary to achieve an SAR or 5 in the Sheely field.

Table 3. Data and calculated values used in Figure 3.

Ted Sheely Farms Field 6-3						
			Na	SAR	Na	Gypsum
Site ID	Ca	Mg	me/l		to replace	Tons
Site 14	2.8	1.0	8.9	6.5	2.04	1.8
Site 19	2.8	1.2	8.8	6.2	1.73	1.6
Site 27	2.8	1.3	10.4	7.3	3.24	2.9
Site 31	5.6	2.9	14.1	6.8	3.79	3.4
Site 86	3.3	1.4	17.6	11.5	9.94	8.9
Site 94	5.1	1.6	10.2	5.6	1.05	0.9
Site 102	7.4	5.8	40.1	15.8	27.25	24.5
Site 144	19.2	6.3	54.7	15.3	36.85	33.2
Site 155	4.3	3.4	21.8	11.1	11.99	10.8
Site 162	3.4	1.9	18.9	11.6	10.76	9.7
Site 174	10.2	7.6	33.1	11.1	18.18	16.4
Site 185	18.4	6.0	50.1	14.3	32.64	29.4

Figure 3 shows the calculated gypsum requirement for the Sheely Farm field as interpolated from the values in Table 3. Unlike the J&J field, in which the salinity pattern is heavily influenced by seepage from a nearby drainage canal, the pattern in the Sheely field appears to be more due to pre-existing conditions in the field.

Discussion

Although it was not statistically significant, the primary yield trend in the experiment was due to the use of a sprinkler for the first irrigation. The advantage of sprinkler irrigation is in leaching the salts to a level below the emerging seed, and thus allowing greater stand establishment. Although there appeared to be a trend toward increased yield in the sprinkler main plot from the gypsum treatment over the control, this effect may have been masked by high experimental variability. In addition, the effects of gypsum may not be evident in the first year following application.

The drainage tiles in this experiment also influenced the results with increased yields in all treatments where the tile was present. Though as seen in Table 2 with plots having multiple samples taken (one at the north end of the field and one at the south) a high sodium replacement value could have a high yield. This averaging of the entire plot yield might also be masking potential beneficial affects from the soil amendments.

Water quality is another issue that needs to be evaluated. The analysis of this data is still being reviewed, but the importance can not be over looked. Without good quality water reclamation of salt affected soil would be very difficult, if not impossible.

This preliminary study show that the use of a preliminary EM-38 survey processed in statical model can generate a soil-sampling plan that allows for optimal soil samples. From this soil samples a soil amendment map can be generated. The incorporation of the NDVI with the EM-38 could possible give even a greater insight to problems that could be encountered not foreseen by an EM-38 survey. (i.e. drainage tiles)

Based on our measurements in the Sheely Farm field we have set up a site-specific amendment experiment for 2001. The central north end of the field had high salinity with a gradual improvement towards the south end (Fig. 3). This area of the field seemed to be ideal for the variable rate application. The experiment for this field was laid out as a randomized complete block with four blocks and six treatments. Each plot consists of 12 rows on a 30" bed. The treatments consist of two amendments, one with gypsum and the other of sulfuric acid. The two amendments have been applied at three varying rates within zones determined by the generated amended site map. The first treatment application rate was 9 tons of Gypsum, 3 tons of sulfuric acid at the northern most zone and no amendments in the following two zones. The second treatment included 6 tons of gypsum, 2 tons of sulfuric acid in the northern zone, 3 tons of gypsum, 1 ton of sulfuric acid in the middle zone and nothing applied in the southern zone. The final treatment was a uniform application in all zones, 3 tons of gypsum, 1 tons of sulfuric acid. The total amount of soil amendment was kept at a constant amount in order to evaluate any cost benefits.

Acknowledgments

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References

Hake, S. J., T. A. Kerby, and K. D. Hake. 1996. *Cotton Production Manual*. Oakland, CA: Division of Agriculture and Natural Resources, University of California.

Lesch, S. M., D. J. Strauss, and J. D. Rhoades. (1995). Spatial prediction of soil salininty using electromagnetic induction techniques: 1. Statistical prediction models: a comparison of multiple linear regression and cokriging. *Water Resources Research*, 31(2): 373-386.

Letey, J. (2000). Soil salinity poses challenges for sustainable agriculture and wildlife. *California Agriculture*, 54(2): 43-48.

Plant, R. E., D. S. Munk, B. R. Roberts, R. L. Vargas, D. W. Rains, R. L. Travis, and R. B. Hutmacher. (2000a). Relationships between remotely sensed reflectance data and cotton growth and yield. *Transactions of the ASAE*, 43(3): 535-546.

Plant, R. E., G. S. Pettygrove, and W. R. Reinert. (2000b). Precision agriculture can increase profits and limit environmental impacts. *California Agriculture*, 54(4): 66-71.

Richards, L. A., editor. (1954). *Diagnosis and Improvement of Saline and Alkali Soils*. Washington, D.C.: US Department of Agriculture.