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Economic Impact of Salinity: The Case of Al-Batinah in Oman

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ABSTRACT

The aim of the study was to investigate how farmers could sustain an economically viable agricultural production in salt-affected areas of Oman. The problem of salinity in the Batinah coastal area, Oman, dates back to the 1990's with the major identified cause being excessive groundwater abstraction. Seawater intrusion in the Batinah aquifers is still advancing at an alarming pace. The present study estimates the on-farm economic losses caused by salinity. The study is based on a sample of 112 farms. Farms were divided into three groups according to the soil salinity levels, low salinity, medium salinity and high salinity. Linear programming was used to maximize each type of farm's gross margin under water, land and labor constraints. The economic losses incurred by farmers due to salinity were estimated by comparing the profitability of the medium and high salinity farms to the low salinity farm's gross margin. Results showed that when salinity increases from low salinity to medium salinity level the damage is US$ 1,604 ha^{-1} and US$ 2,748 ha^{-1} if it increases from medium salinity to high salinity level. Introduction of salt-tolerant crops in the cropping systems show that the improvement in gross margin is substantial thus attractive enough for medium salinity farmers to adopt the new crops and/or varieties to mitigate the effect of water salinity. However, in the high salinity farms the gross margin improvement is too low to encourage farmers to adopt salinity tolerant crop varieties.

Key words: Osmotic stress, damage evaluation, linear programming, salt-tolerant crops, living with salinity

INTRODUCTION

Water and soil salinity problems are widespread in the agricultural sector of many countries, in particular those of arid and semi-arid climates. According to Borsani and Botella (2003), soil salinity has emerged as a main worldwide crop production problem. More than half of the world's groundwater supplies are already saline and the proportion is increasing as demand for water outstrips supply (ICBA, 2003). Rising salinity in the sultanate of Oman is a serious threat to sustainable use of natural resources. Nazir (2005) mentioned that salt-affected soils represent 5% of cropped area. Oman's agricultural expansion since the 1980's has accelerated the use of groundwater through over pumping in coastal areas, thereby disturbing the water balance and resulting in seawater intrusion. High temperature and low rainfall (average rainfall is less than 100 mm $year^{-1}$ and potential annual evapo-transpiration is twenty times higher) are conducive to salt accumulation on the surface and sub-surface of the soil, as salts are not leached out completely.

Farmers were unaware about the quality changes caused by the discrepancy between over-pumping and rainfall recharge. Gradually, soils became salinized and groundwater became more salt concentrated, boosted by seawater intrusion. The phenomenon of groundwater salinization is most likely irreversible in the Batinah region due the existence of depressions in the aquifers. Despite the belief that it is possible that the phenomenon could be reversible, the partial recovery of aquifer quality would necessitate several decades of zero pumping (Zekri, 2008). A number of farms have been abandoned due to salinity levels that were unendurable even to the most salt-tolerant crops. The Sultanate of Oman realized the extent and the impact of the salinity problem. Thus some actions - such as the control of digging new wells and the rehabilitation of older wells, constructing recharge dams and developing incentives for modern irrigation systems-were adopted and implemented (Ministry of Agriculture and Fisheries, 1993). Moreover, saline agriculture has been used in the Sultanate. According to Biosalinity News (2004) research yielded good results for forages and field crops in Al Batinah region.

Despite the considerable efforts made, sufficient scientific information is still required to evaluate the damage caused by salinity. The objectives of this study are to evaluate the economic damage due to groundwater quality degradation at the farm level and to analyze and evaluate the possibility of mitigating the salinity problem by adoption of salt-tolerant crops tested by researchers in Oman at experimental level.

MATERIALS AND METHODS

Linear Programming (LP) is a method used to determine the maximum profit under a set of fixed farm constraints (Hazell and Norton, 1986). Several papers have analyzed the problem of poor water and soil qualities and their effects on farm return. LP was mainly used to estimate the damage resulting from salinity increase. Gardner and Young (1985) have estimated yield variation on poorly drained soil at particular salinity levels, as well as consequences from increased salinity. They used two linear programming models, one reflecting production in the current situation and the other simulating future salinity conditions. The difference in net farm income between the two models provides an estimate of agricultural damage caused by the increase in salinity. Javed *et al.* (1992) used a mathematical model to optimize the alternate use of scarce, good-quality canal water and poor-quality groundwater. The objective function maximizes the total net return. Irrigation water availability, irrigation system capacity, pumping capacity, land availability and crop quota limits were the main constraints of the model. The effect of water salinity on the objective function was taken into consideration through different crop yield levels. Marshall and Jones (1997) used a single-year regional linear programming model. A base line scenario assuming zero salinity was estimated and a second scenario based on predicted levels of soil salinity was elaborated, in order to predict the overall economic impacts of soil salinity. A range of vegetable crops, pastures as well as livestock activities were specified. Estimated salinity yield reduction rates were introduced according to each soil salinity level. The main constraints were water allocation and availability and labor requirements. Input costs, returns as well as technical coefficients, with relation to the salinity levels, were included. Srinivasulu and Satyanarayana (2005) developed an LP model in order to maximize farm net returns in India. Model constraints were land, use of canal water, use of groundwater, irrigation water requirement and land suitability. Water salinity was calculated from canal water, the quantity and quality of groundwater and effective rainfall. The permissible upper limits of mixed water salinity were estimated to 6 and 4 dS m^{-1}, respectively for cotton and the remaining crops.

Study area: Al Batinah coastal area is one of the most highly populated regions of Oman and is the most concentrated farming area of the country with about 52% of land under cultivation. One hundred and twelve farmers were randomly selected and interviewed in seven Willayat of the Batinah during the period from March 2008 to August 2009. Water samples from each farm were collected. Information about income, cropping patterns, livestock activity, labor characteristics and water sources and uses were collected. The results of the statistical analysis were classified into three farm types. For the classification of the surveyed farms, we used Fipps (1996) and Glover (1996) irrigation water classification which consists of three main classes: Low salinity or excellent irrigation water, Moderate salinity or good water and finally high salinity water. The Low Salinity (LS) level corresponds to an Electric Conductivity (EC) of the soil in the root zone less than 2.5 dS m^{-1}. The Medium Salinity (MS) level an EC of the soil in the root zone between 2.5 and 7.5 dS m^{-1} and finally the High Salinity (HS) level an EC of the soil in the root zone higher than 7.5 dS m^{-1}. Since, none of the farms visited had a low salinity level the LS farm class data was obtained from Al-Said *et al*. (2007) which covered the same area of the present study.

Model: Mathematically, the LP model used to estimate farm gross margin for different farm salinity classes is written as follows:

Maximize:

$$\sum(\text{Xcrop (i)} * \text{cropGM (i)}) - \text{Forage. Cost} * \text{Xforage} + \sum(\text{Xanim (a)} * \text{LivestockGM(a)}) - (\text{Purch.Forage} * \text{P.Forag})$$

Subject to:

$$\sum_m \sum_i ((\text{Xcrop(i)} * \text{land occupation(m,i)})) \le \text{total land}$$

$$\sum_m \sum_i \sum_a ((\text{Xcrop(i)} * \text{Labor requirement(m,i)}) + (\text{Xanim(a)} * \text{Labor requirement(m,a)}) \le \text{Aailable Labor(m)}$$

$$\sum_m \sum_i ((\text{Xcrop(i)} * \text{Water requirement(m,i)})) \le \text{Availablewater(m)}$$

$$\text{Xcrop "plantation"} \le \text{observed land for plantation}$$

$$\sum_a (\text{Xanim(a)} * \text{Foragerequirement(a)}) \le \text{X" Forage"} * \text{Forage yield} + \text{Purch Forage}$$

Where:

i	: Crop name
m	: Month
a	: Livestock type
Xcrop	: Crop area (ha)
Xanim	: No. of animals
GM	: Gross margin (O.R ha^{-1})

Purch.Forage : Purchased forage (tons)
P.Forage : Forage price (O.R/ton)

In this model the plantation is considered as a fixed area. Consequently, only annual crops are allowed to vary. This is due to the fact that farmers are not considering reducing the area allocated to plantations, as observed in the survey undertaken.

RESULTS AND DISCUSSION

The LP results obtained for the three farm types are presented in Table 1.

Column 2 shows the optimal crop mix for the LS farm. Most of the area is allocated to plantations, with almost 68% of the farm area. Cucumber comes in second in area followed by forage which occupies the least area. The maximum gross margin per ha for the low salinity farm is $ 5,712. This gross margin will be considered in what follows the benchmark towards which the gross margins of farms affected by salinity will be compared.

Column 3 represents the LP results obtained for the MS type of farms. Vegetables, mainly cucumber and melon, represent 62% of the cropped area followed by forages which represent 22% of the cropped area. The remaining 16% is allocated to plantations. The maximum gross margin of the MS farm is $ 4,108 ha^{-1} with labor as the main constraint. Finally, column 4 represents the LP optimum for the HS farm. The area allocated to plantations represents 18% of the farm total area, while vegetables represented only by pepper occupy 77% of the cropped area. Finally, forages represent only 5% of the total farm area.

Losses due to salinity: Figure 1 shows the gross margins of the three farm types as well as the losses due to salinity. The loss is estimated as the difference between LS farm gross margin and

Table 1: Linear programming models' results for the three farm types

Crop area (ha)	LS base line scenario	MS base line scenario	HS base line scenario
Date palm	1.33	1.31	0.79
Lemon	0.16		0.09
Mango	0.42	0.21	0.06
Banana		0.21	0.12
Forage	0.22	2.4	0.27
Cucumber	0.69	3.33	
Melon		3.33	
Onion			
Pepper			4.48
Tomato			
Watermelon			
Total area	2.82	10.8	5.82
Cattle (heads)	3	26	9
Goat (heads)	0	0	0
Sheep (heads)	0	0	0
Gross margin ($ ha^{-1})	5,712	4,108	1,360
Opportunity cost of water in ($ m^{-3})	0	0	0.22
Opportunity cost of land ($ ha^{-1})	0	0	55
Opportunity cost of labor ($ day^{-1})	9	5.66	2.85
Water use in (m^{3} ha^{-1})	24,607	14,019	10,594

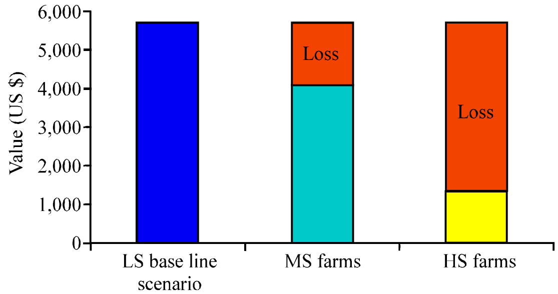

Fig. 1: Farm gross margins according to salinity level

the other two farms' gross margins, respectively. Consequently, the damage caused by salinity in the MS farm is evaluated at \$ 1,604 ha^{-1} or a loss of 28% compared to the LS farm. The loss reaches \$ 4,352 ha^{-1} or 67% of the gross margin for the HS.

Potential impacts of salt-tolerant crops on farmers' income: In order to address the problem of salinity, research has focused on introducing salt tolerant crops and varieties. Applied research on salt-tolerant crops was based on-field testing of tomato as well as barley, pearl millet and sorghum during the period 2007-2009. A salt-tolerant tomato variety using three fertilizing methods as well as barley, pearl millet and sorghum were irrigated with 6 and 9 dS m^{-1} of water salinity. The obtained experimental results of salt-tolerant crops tested in Al Rumais Agricultural Research Station were introduced to the LP model with the objective of evaluating their feasibility at farm level and competitiveness with the existing crops and varieties. The same LP models were used adding to the existing crops the new crops and/or varieties. The results of the models with salt-tolerant crops are shown in Table 2 and 3. Two scenarios are considered for each type of farm: vegetables-restricted and vegetables-non-restricted model. The restricted model has an additional ad-hoc constraint on the area allocated to vegetables, due to marketing difficulties. In this scenario the area allocated to vegetables should not exceed the observed area obtained from the survey. In the non-restricted model the area allocated to vegetables is not restricted.

Rows with the grey cells in Table 2 and 3 indicate the business as usual scenarios (before introducing salt-tolerant crops) which will be compared to the scenarios listed previously.

Results show that MS farm gross margin can be improved by up to \$ 1,147 ha^{-1} compared to the MS base line scenario. This represents an increase of 28% in the gross margin. Salt-tolerant tomato with inorganic fertilizers replaces cucumber and melon crops. This shows that the tested tomato variety is very competitive. In fact the reduced cost of cucumber and melon are \$ 2,621 ha^{-1} and \$ 2,569 ha^{-1}, respectively. On the other hand the existing forages are substituted totally with pearl millet with a substantial increase in the allocated area.

In the unrestricted scenario the gross margin could be increased by up to 40% compared to the MS base line scenario. The salt-tolerant tomato variety, with inorganic fertilizers is selected by the LP model to replace the cucumber and melon with a slightly bigger area than the restricted model above. Pearl millet is again the only forage crop selected in the crop mix and replaces the existing forages.

In the absence of vegetables restriction the cropping intensity reaches 130%. The livestock activity in the unrestricted scenario is reduced to 21 heads of cattle instead of 26 heads in the MS base line scenario. Figure 2 compares the LS base line scenario to the MS scenarios. The Fig. 2

Table 2: Optimal solutions for MS farm type considering salt-tolerant crops

Crop area (ha)	MS base line scenario	Adjusted MS scenario with vegetable restrictions	Unrestricted MS scenario
Date	1.31	1.31	1.31
Mango	0.21	0.21	0.21
Banana	0.21	0.21	0.21
Forage	2.4		
Cucumber	3.33		3.2
Melon	3.33		
Onion			
Pepper			
Watermelon			
Salt tolerant tomato (inorganic at 6 dS m^{-1})		5.45	5.86
Salt tolerant tomato (organic at 6 dS m^{-1})			
Salt tolerant tomato (mixed at 6 dS m^{-1})			
Salt tolerant sorghum (6 dS m^{-1})			
Salt tolerant pear millet (6 dS m^{-1})		3.61	3.2
Salt tolerant barley (6 dS m^{-1})			
Total area	10.8	10.8	10.8
Cattle (heads)	26	24	21
Goat (heads)			
Sheep (heads)			
Gross margin/ ha (US$)	4,108	5,255	5,733
Gross margin increase in $ ha^{-1} compared to MS base line scenario		1,147 (28%)	1,625 (40%)
Opportunity cost of water (US$/$m^3$)			
Opportunity cost of land (US$ ha^{-1})		2,725	3,203
Opportunity cost of labor (US$ day^{-1})	5.66	19.14	
Water use (m^3 ha^{-1})	14,019	12,808	13,120

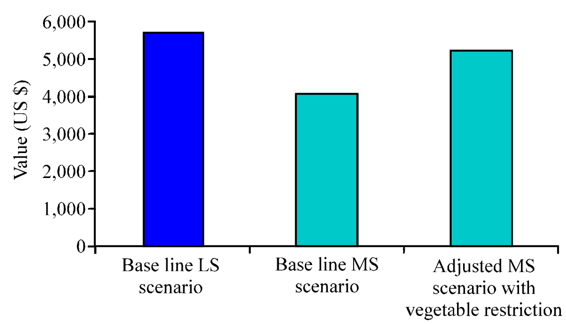

Fig. 2: MS Farm gross margin improvement after introducing salt-tolerant crops

shows that the losses due to salinity in the MS farms could be reduced to only 8%, instead of 28%. In other terms the losses due to salinity would be only $ 457 ha^{-1} if farmers adopt the salt tolerant crops instead of $ 1,604 ha^{-1}. These results show that there is a potential to help farmers out of the salinity problem by adopting pearl millet instead of the usual forages and the salt tolerant tomato variety instead of the current vegetables represented mainly by cucumber and melon.

Both the unrestricted and restricted scenarios for the HS farms resulted in improvements of the overall farm gross margin by $ 801 ha^{-1} and $ 372 ha^{-1} compared to the HS base line scenario,

Table 3: LP optimized solution for HS farms with salt-tolerant crops

	Adjusted HS scenario with	Unrestricted	
Crop area (ha)	Base line HS scenario	vegetable restrictions	HS
Date	0.79	0.79	0.79
Lemon	0.09	0.09	0.09
Mango	0.06	0.06	0.06
Banana	0.12	0.12	0.12
Forage	0.27		
Cucumber			0.49
Melon			
Onion			
Pepper	4.48		
Watermelon			
Salt tolerant tomato (organic at 9 dS m^{-1})			
Salt tolerant tomato (inorganic at 9 dS m^{-1})			
Salt tolerant tomato (mixed at 9 dS m^{-1})		1.58	4.25
Salt tolerant sorghum (9 dS m^{-1})			
Salt tolerant pearl millet (9 dS m^{-1})		1.15	0.49
Salt tolerant barley (9 dS m^{-1})			
Total area	5.82	5.82	5.82
Cattle (heads)	9	4	1
Goat (heads)			
Sheep (heads)		11	10
Gross margin in ($ ha^{-1})	1,360	1,732	2,161
Gross margin increase in $ ha^{-1} compared to HS base line scenario	0	372 (27%)	801 (59%)
Opportunity cost of water ($ m^{-3})	0.22	0.20	0.13
Opportunity cost of land ($ ha^{-1})	55		1,061
Opportunity cost of labor ($ day^{-1})	2.85	9.91	9.91
Water use in m^3 ha^{-1}	10,594	10,594	10,594

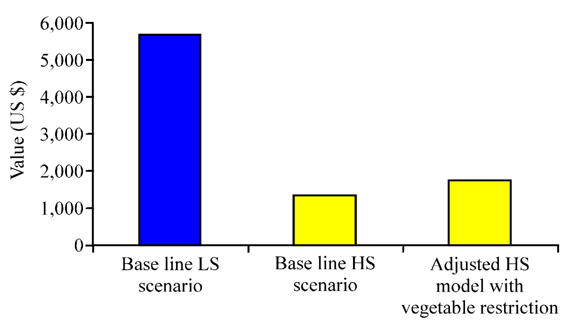

Fig. 3: HS Farm gross margin improvement after introducing salt-tolerant crops

respectively. Similarly to the MS results the salt-tolerant tomato variety is selected instead of the pepper crop. The area allocated to local forage crops in the basic LP model for HS farms is replaced by pearl millet.

The losses caused by salinity in the HS farm class are very high to be mitigated by the introduction of salt tolerant crops and/or varieties. Figure 3 shows that the gross margin of the adjusted model with salt-tolerant crops is $ 1,732 ha^{-1} compared to $ 5,712 ha^{-1} for the LS farms.

Consequently the introduction of salt tolerant crops in the HS farms does not allow a substantial improvement in the gross margin in such a way to mitigate salinity and sustain agriculture in such types of farms. Consequently our results show that despite the consideration of salt tolerant crops, if the salinity reaches an EC level in the root zone higher than 7.5 dS m^{-1} agriculture may not be sustainable.

CONCLUSIONS

The economic losses resulting from groundwater quality degradation were estimated using the (LP) approach maximizing gross margin for three farm types under water, land and labor constraints. Losses incurred by farmers due to salinity were estimated at \$ 1,604 ha^{-1} (28%) if salinity increases from low salinity to medium salinity level and \$ 4,352 ha^{-1} (76%) if it jumps from low salinity to high salinity level.

The research on salt-tolerant crops tested in the Rumais Research Center during 2007-2009, represented by a salt tolerant tomato variety and three forage crops (sorghum, pearl-millet and barley), are incorporated into the LP models to test for their possible adoption by farmers. Results showed that the salt tolerant tomato variety is retained in the crop mix in the MS farms covering 50% of the cropped land. Pear-millet forage replaces the existing forages and occupies 30% of the cropped area. Consequently, the farm gross margin is improved by 28%. The results show that the improvement in gross margin is quite substantial thus attractive enough for MS farmers to adopt the new crops and varieties to mitigate the effect of water salinity.

In the HS farms, results showed that the salt-tolerant tomato is retained in the crop mix and can cover up to 27% of the cropped land. Pear-millet forage is also retained and can cover up to 20% of the cropped area. This would result in an improvement of the gross margin by 27 compared to the base line HS scenario. Such improvement is not enough to mitigate the effect of salinity and provide farmers with a concrete solution. This result shows the incapacity of mitigating the salinity effect after a threshold level by adopting higher salt tolerant crops. Thus the future of the HS farms is gloomy.

The LP models showed that groundwater is not always fully used and even if it is so, its opportunity cost is very low. One can conclude that farmers are not suffering from a groundwater shortage. In fact, it is the phenomenon of seawater intrusion caused by over-pumping of fresh groundwater that is causing groundwater quality degradation. Consequently, more research is needed to address the problem of ways to stop seawater intrusion in a proactive fashion. The adoption of salt-tolerant crops can help mitigate the problem in the medium run, but it seems far from being a solution as long as seawater intrusion is not addressed.

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