Saline and Alkali Soils in Peru

A. ZAVALETA

Agrarian University, La Molina, Lima, Peru

At many places along the Peruvian Coast the remains left by the earliest people known to have established substantial permanent settlements in the region are found. The date of their first appearance is not quite certain; they were undoubtedly there by 2000 B.C., and probably as early as 2500 B.C. BUSHNELL states [4] "Handfuls of hard saline clay were used in constructing single-roomed houses", hence salt affected soils appear as early as agriculture.

At the Late Formative Period 250 A.D. there was an improvement in agricultural methods. Evidence from the Viru Valley shows that irrigation developed rapidly in the later part of the period, although it is doubtful if it was practiced at the beginning. In the Gallinazo or Viru Period there were great developments. The main irrigation canals seem to have developed in this period and some cultivation plots connected by narrow canals can still be seen. The number and distribution of the sites suggest a great increase of population, made possible by irrigation, which in turn imposed the necessity for a closely integrated society, since an elaborate system of canals can only be maintained and the water shared out, by strict control. Among others, a great earthen canal in Chimica, which is 74 miles long and still irrigates some fields near Chan Chan, the Chimu capital, is believed to date from 500 A.D. [8]. The danger of salinity was pointed out, since the beginning of this century by SUTTON and PORTOCARRERO (1902), KLINGE 1940—1947; FLORES and RODRIGUEZ 1951; STUART 1962; ZAVALETA 1964 and by other scientists in a Salinity Symposium organized by IICA, OEA, La Molina, 1966.

Causes of salt affected soils

Agriculture is developed in the Peruvian arid coast along 54 main alluvial valleys of very fertile, and productive soils which are mostly flat or with minimal slopes. Excess water from the western Cordillera de los Andes flowing across the valleys in rivers and rivulets, is the main source of irrigation water. Forty-eight rivers present periodical flow, from October or November through March or April, and 4 are of permanent flow. Agriculture from the coast accounts for 60 per cent of the national agricultural production, and 30 per cent of the gross national product. The soil and climatic conditions permit the growth of any subtropical crop.

Most agricultural products were intended for internal consumption up to the beginning of this century, consequently only a low proportion of the total soils were cultivated. Due to world conflicts, the land cropped increased because some Peruvian agricultural products were needed, and at the same time over-irrigation increased too.

Later on, some agricultural products were exported, land use was intensified, and new irrigation areas were developed. A lack of scientific and technical knowledge led to over-irrigation. A rise of the ground water table due to climatic, and topographic conditions, the excess of moisture and evapotranspiration during the summer months, caused salt affected soils to develop in low positions. In a few valleys of marine origin (Pucchon, Camanâ) poor drainage conditions are created by the high water table caused by sea water. In some places in the highlands (sierra) bordering Titicaca Lake, salt affected soils have been detected; the sourrounding hills are the source of salts. The above conditions appear to be the main factors causing salinization and the accumulation of alkali salts [13] in Peru. However the irrigation of flat virgin lands has caused some problems in irrigation agriculture.

Interpretation of salt affected soils

Interpretation of salt affected soils is based on a soil survey and for the classification, three factors are considered: pH, electric conductivity of the saturation extract expressed in mmhos/cm. at 25 °C (E.C. $\times 10^3$), exchangeable sodium percentage (Table 1).

Table 1

Classification of soils based on the adaptation of standards used by the U.S.D.A. Soil Salinity Laboratory, Riverside, California

Type of soil	Salinity E.C.$\times 10^3$	Alkalinity	
		ESP	pH
Saline soils	>4	<15	<8.5
Saline-alkali soils	>4	>15	<8.5
Nonsaline-alkali soils		>15	>8.5

Main characteristics of salt affected soils

Data from recent studies of typical salt affected soils of northern, central and southern Peruvian coastal valleys are presented in Table 2.

From the data in Table 2 the following conclusions are drawn:

1. In the four regions surveyed 20 to 100 per cent of the arable soil is affected by salts.

2. All types of salt affected patterns and their transitional forms occur.

3. One irrigated area is 100 per cent affected by salts due to its marine parent material.

4. The hazard of salinity is increasing. The Santa Rosa Irrigation project, only 15 years old, is now 20.5 per cent salt affected.

From laboratory data and some experiments in the field, it is further concluded that:

5. The lowest electrical conductivity observed in the saline soils is 4 mmhos/cm. and the greatest over 400 mmhos/cm. It is common to find good crops growing in soils with a minimum electrical conductivity of over 16 mmhos/cm. and containing 400 to 1200 me/l of chlorides in the saturation extract.

Table 2

Some salt affected soils of Peru

Region	Location	Hectares Surveyed	Irriga- tion	Percentage of various soils						Poorly drai- ned %
				Nor- mal	Saline	Saline Alkali	Non Saline Alkali	Soloth	Total	
Northern	Low Piura Valley [12,5]	23000	old	25.0	21.2	37.5	15.8	—	75.0	67
Central	Santa Rosa Irriga- tion [2]	6500	15 years old	79.5	2.0	6.0	12.5	—	20.5	18
Southern	Average of 14 Southern Alluvial Valleys [9]	85500	old	16.9	4.0	59.9	18.4	—	83.1	22.7
Southern	Majes, Siguas La Joya, Irrigation Proj. [15]	250000	non irrig.	0.0	89.4	0.0	0.0	10.6	100.0	0.0

6. Alkali soils in Peru rarely exhibit pH values in excess of 8.8; Santa Rosa Irrigation is a light textured soil low in organic matter and it is the only soil to exhibit a pH value over 9.0.

7. Alkali soils in Peru have high sodium-salt salinity, they have a high exchangeable sodium percentage in the soil complex, (15—60%), but morphologically and physically they are not sodic soils. There is no sodium carbonate salinity; none of the "black alkali" described in other part of the world have been found.

8. Slight negative effects have been observed in the germination of cotton and pastures in soils with an exchangeable sodium content between 15 and 25 per cent, but for the rest of the vegetative period the plants showed normal growth and yields.

9. Humus stained incrustations are extremely rare and translocated humus accumulations in profiles are rarely seen.

10. The saturation extract determination shows that chlorides and sulphates are dominant anions (attaining in some cases 4740 me/l of chlorides and 341 me/l. of sulphates) and that sodium was the predominant cation (up to 3960 me/l. in non-irrigated areas).

11. The distribution of clay is due to depositional differences and the kind and amount is variable in each soil. In order of decreasing abundance mica, feldspar, kaolinite, chlorite, vermiculite, montmorillonite, some interstratified vermiculite-chlorite, mica-chlorite, montmorillonite-vermiculite and mica-vermiculite were identified. In a salt affected volcanic parent material the X-ray patterns do not correspond to any clay mineral known [14].

12. Cotton and alfalfa have been found growing on southern Peruvian coast soils that contain 25 to 50 ppm. hot water soluble boron without exhibiting toxicity symptoms. It seems possible that the tolerance of cotton and alfalfa to high concentrations may be related to the high pH and Ca levels also found in these soils. Many soils contain more than 3 ppm. hot water soluble boron and in some areas the content is 500 times higher than the safe limit of 1.5 ppm. [15]. From studies of the effect of calcium and pH on

Table 3
Classification of irrigation waters

Factor	Excellent		Good	Dangerous		Unsatisfactory
E.C. × 10^6 at 25° C	0—250	250—750	750—2250	2250—4000	4000—6000	>6000
Salinity hazard (C)*	C1	C2	C3	C4	C5	C6
B ppm						
no tolerant crops	0.6—1.3		1.3—2	2—2.5		>2.5
tolerant crops	1 —2		2 —3	3.—3.7		>3.7
Sodium	Low		Medium	High		very high
Alkali hazard (S)**	S1		S2	S3		S4
Residual						
Na_2CO_3	less than 1.2		less than 1.2	1.2—2.5		>2.5

* Salt concentration.
** Sodium concentration.

boron uptake from high concentrations of boron by cotton and alfalfa using southern Peruvian soil samples, it was concluded that a high pH accompanied by a high Ca concentration resulted in a 50 per cent lowering of the boron

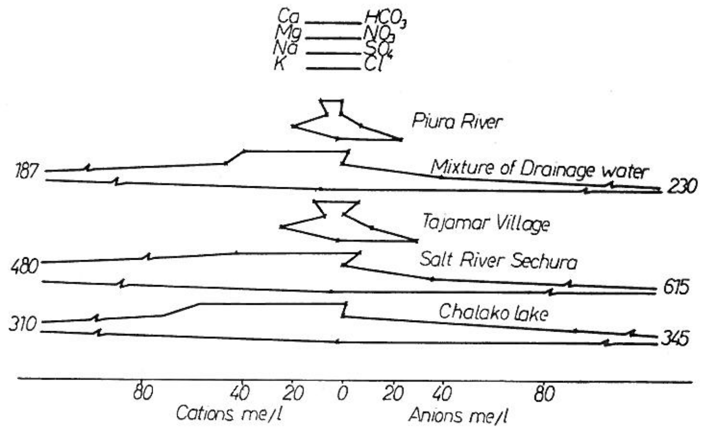

Fig. 1

Chemical analysis of irrigation and drainage water in the Piura valley Northern Peru

uptake by cotton plants. High Ca concentrations or high pH treatments applied separately had no influence on the absorption rate. The boron content of alfalfa was not significantly affected by changes in the pH and Ca concentration of the nutrient media. These results suggest that the boron absorption mechanism of the cotton plants was affected by the presence of high concentrations of Ca and OH-ions, or that the availability of boron was affected by the secretion of H and/or CO_2 by the roots [6].

Water supply

Rivers originating in the Western Andes constitute almost the entire irrigation supply for the coastal alluvial valleys, with only local small supplemental amounts being pumped from wells or drains. During the flood season there is abundance of water and only 4 per cent of the available volume is used, but during the dry season water flow is very limited. The salinity status of water for irrigation on the Peruvian coast is very variable. Quality is evaluated on the basis of the data in Table 3.

According to the classification of irrigation water (Table 3) and the data in Table 4, and Fig. 1 the Piura River at the Mocará bridge, has medium saline water (C2), with a medium-sodium content (S2). However, due to the poor drainage conditions of most soils in the valley, the water is not good for agricultural use and for the same reason the other samples are also unsuitable.

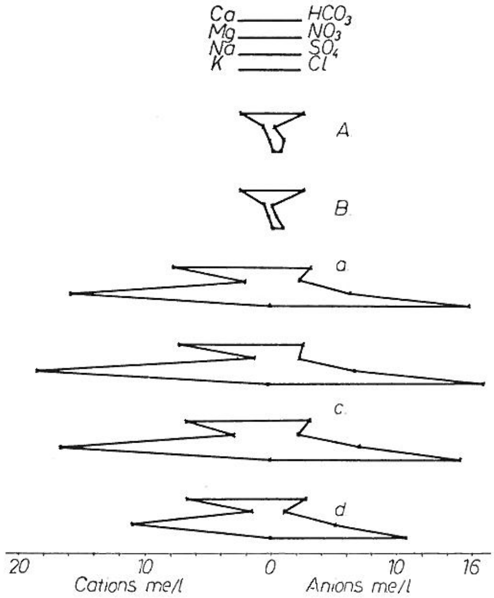

Fig. 2

Chemical analysis of irrigation and drainage water at the Santa Rosa irrigation project, central Peruvian coast. A) Entrance to the irrigation Canal. B) Entrance to the irrigation. Water of drainage: a) at the irrgation; b) at Animas Plain; c) Across north Pan-American highway and drainage canal; d) at dry river

Table 5 shows the analyses of the irrigation and drainage water in the Santa Rosa Irrigation district on the Central Peruvian Coast. The first two samples indicate that there is no change in quality along 28 km of the main canal. The waters are classified as having medium-salinity (C2) and a low-sodium content (S1). The permeability and light texture of the soils permit their irrigation. Na content is low in relation to Ca and Mg content, therefore there is no problem with sodium content. The next two samples are of seepage water and the two last are of surface runoff from the irrigation system.

The increase of sodium and chloride in drainage waters is shown in Fig. 2. Drainage water at the irrigation project and Dry River classified as C2, S2 and it is reused as irrigation water by small farmers. It is plained to use the water drained at Animas Plain C4 S3 for a cooperative system of irrigation.

Table 4

Chemical composition of irrigation water and drainage water at Piura Valley, Northern Peru

	Location				
	Puiza River Mocará Bridge	Tajamar Village	Bellavista Mixture of Drainages	Sechura Salt River	La Union Chalaco Lake
EC × 10^3 at 25°C Mmhos/cm	3.24	4.07	24.4	54.3	35.2
pH	7.9	7.2	7.0	7.7	7.2
Ca^{2+} me/l	8.5	12.0	39.0	42.0	57.0
Mg^{2+} me/l	5.5	7.0	46.0	133.0	71.0
Na^+ me/l	19.6	25.6	187.0	480.0	310.0
K^+ me/l	0.14	0.19	0.8	4.3	1.7
Sum of cations	33.7	44.80	273.0	659.0	440.0
HCO_3^- me/l	1.30	2.75	2.8	7.75	1.60
NO_3^- me/l	0.0	Traces	0.0	0.0	0.0
SO_4^{2-} me/l	8.0	12.0	40.0	36.0	93.0
Cl^- me/l	24.0	30.25	230.0	615.0	345.0
CO^{2-} me/l	—	—	—	—	—
Sum of anions me/l	33.3	45.00	272.8	658.75	339.60
SSP	—	—	—	—	—
SAR	7.4	8.5	28.7	51.2	38.6
Residual Na_2CO_3 me/l	—	—	—	—	—
B ppm.	—	—	—	—	—
Classification	C_2S_2	C_5S_3	C_5S_4	C_5S_5	C_5S_4

The water from across the Northern Pan-American Highway is drainage water C4 S3, without any agricultural use. It causes very accelerated soil erosion. Fig. 3 shows the monthly amount of irrigation water, the loss by seepage and the amount of water lost by evapo-transpiration. From May through September there is a critical situation for agriculture. Almost the same amount of water applied for irrigation is lost by seepage. Fig. 3 shows no change in the quality of irrigation water through the year, but the amount of drainage water decreases from May to June and after that stays almost constant. The highest modulus of irrigation is used from December to March.

The chemical analyses of well water used in irrigation are presented in Table 6.

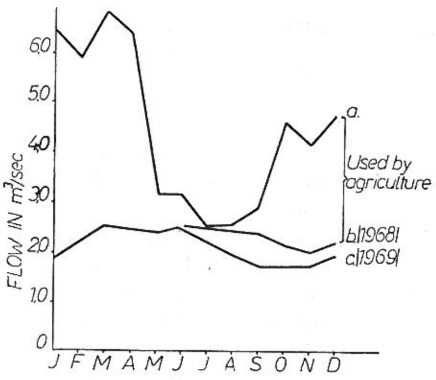

Fig. 3/1

a) Monthly amount of water received for irrigation and b)—c) lost by seepage

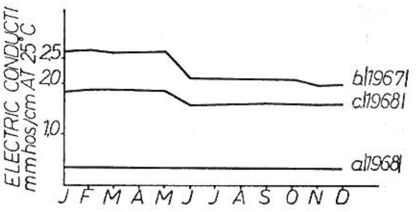

Fig. 3/2

a) Quality of irrigation water and b) quality of seepage water at Animas and c) at dry river

Table 5

Chemical composition of irrigation water and drainage water at Santa Rosa irrigation, Central Peruvian Coast

	Water of Irrigation		Water of drainage at			
	Haura River at entrance to the main Irrigation canal	Entrance to the Irrigation	Irrigation	Animas Plain	Across North Panamerican Highway	Dry River
EC × 10^3 at 25°C	0.33	0.32	2.22	2.66	2.34	1.87
pH	7.9	7.7	7.4	7.5	7.9	8.2
Ca^{2+} me/l	2.7	2.6	8.0	7.4	7.0	7.8
Mg^{2+} me/l	0.8	0.6	2.0	1.4	3.0	1.4
Na^{+} me/l	0.32	0.34	16.2	18.6	16.8	11.2
K^{+} me/l	0.04	0.05	0.26	0.36	0.24	0.13
Sum of cations	3.80	3.59	16.46	27.76	27.04	19.5
CO_3^{2-} me/l	0.0	0.0	0.0	0.0	0.0	0.0
HCO_3^- me/l	2.4	2.4	3.0	2.4	3.0	2.8
NO_3^- me/l	0.0	0.0	2.0	2.0	2.0	1.0
SO_4^{2-} me/l	0.8	0.3	5.9	6.5	7.0	5.1
Cl^- me/l	0.6	0.8	15.5	16.8	16.0	10.6
Sum of anions me/l	3.8	3.5	26.4	27.7	27.0	19.5
SSP	0.36	0.45	1.63	1.89	1.66	—
SAR	0.24	0.26	7.20	8.86	7.50	0.55
Residual Na_2CO_3 me/l	0.0	0.0	0.0	0.0	0.0	0.0
B ppm.	—	—	—	—	—	—
Classification	C_2S_1	C_2S_1	C_3S_2	C_4S_3	C_4S_3	C_3S_2

The Tambo river reaches its greatest flow in January and February with a range of 85,000 to 300,000 l/sec. and the lowest flow is in October—November when the flow is 7,000 to 13,000 l/sec. Fig. 5 shows monthly salinity and boron distribution of the waters of this river. From March through

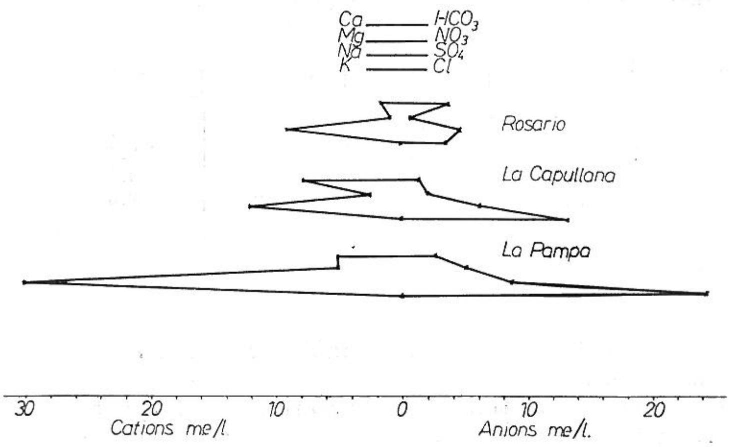

Fig. 4

Chemical analysis of water from wells used for irrigation purposes at Santa Rosa irrigation project on the central Peruvian coast

Table 6

Chemical composition of water used in irrigation on the well Central Peruvian Coast

	Well number						
	1	2	3	4	5	6	7
EC × 10^3 at 25°C	0.99	0.86	0.87	2.02	1.23	1.04	3.28
pH	6.9	7.7	8.3	7.5	7.8	7.8	7.8
Ca^{2+} me/l	1.6	2.0	0.4	7.8	3.2	2.2	5.0
Mg^{2+} me/l	1.0	1.0	0.1	2.4	0.8	0.2	5.0
Na^+ me/l	9.2	7.4	9.6	12.0	9.7	9.7	29.6
K^+ me/l	0.12	0.06	0.08	0.22	0.10	0.16	0.24
Sum of cations	11.92	10.46	10.1	22.4	13.8	12.2	39.84
CO_3^- me/l	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HCO_3^- me/l	3.6	3.0	3.6	1.4	3.4	3.4	2.5
NO_3^- me/l	0.5	0.5	1.0	2.0	1.0	0.5	4.0
SO_4^{2-} me/l	4.4	2.5	1.7	5.8	3.2	3.9	8.3
Cl^- me/l	3.4	4.4	3.8	13.2	6.2	4.4	24.0
Sum of anions me/l	11.9	10.4	10.1	22.4	13.8	12.2	39.8
SAR	8.85	6.06	19.2	5.3	6.86	8.86	13.2
Residual Na_2CO_3 me/l	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B ppm.	—	—	—	—	—	—	—
Classification	C_3S_2	C_3S_2	C_3S_4	C_3S_2	C_3S_2	C_3S_2	C_4S_4

November salt and boron concentration increase and correspond to the least flow, while the salt and boron concentration decrease from January through March, and correspond to the greatest flow. From Fig. 6 it is observed that the lowest quantity of cations occurs in this irrigation water during March, while in November the concentration increases about 5 times.

Table 7

Characteristics of flow of the Tambo River in four years, expressed by monthly averages in thousand liters per second, during four years and the average of seven years [1]

Month	1963	1964	1965	1966	1960—1966 (ave.)
October	13.3	9.2	9.9	8.7	10.2
November	8.6	11.5	7.0	7.5	9.8
January	121.0	34.6	14.7	7.4	83.2
February	291.8	65.6	33.2	16.6	100.2

Notes

1. Samples 99 through 109 were taken from hot spring water around the Vagabundo river.
2. Sample 108 shows that Vagabundo river has low boron concentration before receiving the spring water.
3. Sample 96 represents the irrigation water used at Chucarapi Farm.
4. Samples 93, 94 and 95 represent drainage water, at the Chucarapi Irrigation Farm.

Table 8

Boron in Tambo river basin (Source G. Wiegering, 1965)

Vagabundo River [1] Water Sample No	B ppm	Tambo River [3] Water Sample N°	B ppm
99	17.4	96	6.3
100	16.3		
101	16.2	Tambo Valley [4]	
102	21.6	Water Sample	B
103	15.8	N°	ppm
104	20.8	93	6.1
105	11.6	94	5.8
106	20.8	95	4.3
107	6.6		
108 [2]	1.3		
109	15.6		

From the data in Table 8 it is concluded that Tambo river used as a source of irrigation water has a concentration of boron too high for agriculture purpose and that the main source of boron is its tributary fed by the Carumas hot springs.

In this same valley there is degradation of water due the reutilization of drainage water. This degradation is shown in Table 9.

Fig. 5

Quality of irrigation water and boron content at Tambo valley Southern Peru

The data in Table 9 show that the quality of water during August 1967 was suitable at the highest point, dangerous (C4 S2) at the Chucarapi Farm and very dangerous at the lowest location in the valley. With the lowest quality water a decrease in crop yields of at least a 50% is likely because of the high boron concentration, from August through January. Apparently the use of saline water in Tambo valley was possible until a few years ago, because of:

1. The nature of the soils: good natural drainage, and high permeability.
2. Seasonal abundance of water: great quantities of water were used in irrigation producing leaching and no salt accumulation.
3. Rotation of tolerant crops with rice and alfalfa.

Table 9

Degradation of the quality of the irrigation water [1]

Location in relation to the Valley	Location	EC × 10^6	B ppm	Classification	
The highest	High Carumas	360	1.3	C2S1	Good
High	Chucarapi Farm	2480	4.7	C4S2	Dangerous
Middle	Cocachacra	2400	4.7	C4S2	Dangerous
Middle	San Francisco Javier Farm	2450	4.7	C4S2	Dangerous
Middle	Ensenada Cocachacra canal	2480	4.5	C4S2	Dangerous
Middle	Cocachacra	2480	4.7	C4S2	Dangerous
Low Medium	Arenal	2790	5.7	C4S2	Very dangerous
Low	Arenal	2850	4.2	C4S2	Very dangerous
Low	Curva	2560	5.2	C4S2	Very dangerous
Low	Punta de Bombón	2930	4.5	C4S2	Very dangerous

Reclamation of soils

Along the Peruvian arid coast there are soils suitable for irrigation, but generally they are affected by salts therefore they need reclamation before production. Leaching is obligatory before cropping.

The results of a field experiment are briefly presented in Table 10. This experiment was planned with the following objectives: to determine the effect of leaching by 4 different levels of water ($L1 = 10$ cm, $L2 = 20$ cm, $L0 = 25$

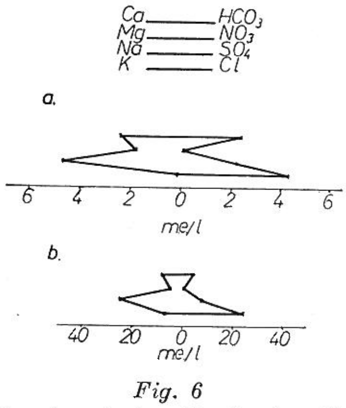

Fig. 6

a) Chemical analysis of Tambo river during March when there is the least conductivity the least amount of B and the highest flow and b) during November when there is the highest amount of B, generally the highest salt concentration and the least flow

cm, $L3 = 30$ cm and $T = 0$ cm) applied at weekly intervals 4 times; the effect of leaching on the adaptability of four crops: alfalfa, potatoes, wheat and forage corn; the effect of the addition of manure on crop yields and the water consumption by each crop. The following conclusions were drawn.

1. The amount of water used for leaching did not significantly influence the amount of salts that remained after leaching.

Table 10

The effect of leaching and manure on crop yields and water consumption

Ranking	Salinity after 4th leaching 0—20 cm	mmhos/cm	Decreasing rank of yields			
			Alfalfa	Potatoes	Wheat	Forage corn
1	L2	4.9	L1	L3	L1	L0
2	L3	4.0	L3	L0	L2	L1
3	L0	4.3	T	L1	L3	L3
4	L1	10.6	L0	L2	T	L2
5	T	17.0	L2	T	L0	T

2. The residual salt content in the soil surface after leaching was not related to the yield of the different crops.

3. The addition of 15 ton/ha of manure improved crop yields and the physical characteristics of the soil.

4. After harvesting, the salt content of the soil was between 3.7 and 6.1 mmhos/cm.

Conclusions

1. In Peruvian soils 1000 ppm B was found in hot water extracts (Sama valley).

2. The two critical factors which arrest agricultural development are over-irrigation in the upper valleys and the use of the ground water in the lower valleys. As a result of either, salinity problems appear and affect the prosperity of the region. Therefore land classification and drainage surveys are of primary importance. Since most of the soils in Southern Peru have a high content of gypsum, which make reclamation work much easier, only leaching and drainage operations based on land classification will be carried out there.

3. Crops grown in Southern Peru are quite resistant to salinity. Research work should be carried out to determine if this resistance is due to the increased salt tolerance of the plants or to the favourable balance of salts in the soil. It may be more important to consider the relative composition of the salt content than its total concentration.

Recommendations

1. Diagnostic studies of the salt affected soils in each valley are of pressing importance.

2. Amelioration practices should be started immediately in order to avoid crop losses.

3. Drainage studies in each valley should be carried out in connection with salinity studies. Main drainage systems must be built by the government and secondary ones by the owners of the land.

4. Irrigation of the crops should be carried out according to crop requirements and the nature of the soils and climate.

5. To prevent the over-irrigation of farms during water abundance the construction of regulator dams on upper rivers in necessary.

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