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Enhancement of Salinity Tolerance of Pea by P Fertilisation - A Radiotracer Study -

RAJ SINGH MALIK, ANAND PRAKASH GUPTA,
SILVIA HANEKLAUS and NASIR EL BASSAM

Institute of Crop and Grassland Science

1 Introduction

Irrigation practices began about 2500 years ago and have increased dramatically during the past 30 years (Postel, 1989). Although they have contributed substantially to increases in world agricultural productivity, they also resulted in increasing salinisation and water logging of agricultural land in some areas and consequently their complete destruction (van Schilfgaarde, 1984). It is estimated that 10 percent of the world's cropland are affected by salinity. Of the irrigated lands, as much as 20-27 percent may be salt affected and up to 37 per cent may be saline, sodic or waterlogged (Ghassemi et al., 1995). Of the total 380 million hectares of saline soils, 140 million hectares are highly saline. In arid and semi-arid areas of the world approximately one third of developed arable lands envisage some degree of problems associated with salt accumulation.

One of the major approach to control salinity has been to leach soluble salts from the soil profile by irrigation with high quality water. But this practice is no longer acceptable because of increased salt content in streams due to irrigation returns, rising water table and limited water resources. One of the cost-effective strategies to cope with salinity involves growing plants that have the inherent ability to tolerate a saline environment. But owing to excessive spatial and temporal variations in the salt concentration, this attempt has been relatively unsuccessful (Holm, 1983). For the last few years the possibility to mitigate salinity hazard by nutritional factors has been studied. Phosphorus nutrition has been implicated in modifying the effect of salinity upon growth of glycophytes (Feigin, 1985). Phosphorus/salinity interactions have been reported from an induced enhancement (Awad et al., 1990 and Mor and Manchanda, 1992) to create antagonism (Cerda et al., 1977 and Cerda and Bingham, 1978) while other studies report no interaction between phosphorus and salinity (Termaat and Munns, 1986).

Table 1: Important physico-chemical properties of the soil used for the experiment

1	Soil texture			
	a) Sand	(%)	:	90.80
	b) Silt	(%)	:	8.20
	c) Clay	(%)	:	1.00
2	Soil type		:	Sand
3	Taxonomic class		:	Typic Torripsament
4	Saturation capacity	(%)	:	30.00
5	pH	(1:2)	:	7.77
6	EC_e	(dSm^{-1})	:	1.66
7	$CaCO_3$	(%)		Traces
8	Organic carbon	(%)	:	0.05
9	Available N	($mg\ kg^{-1}$)		70.00
10	Available P	($mg\ kg^{-1}$)	:	3.52
11	Water soluble K	($mg\ kg^{-1}$)	:	6.20
12	Morghan's S	($mg\ kg^{-1}$)	:	12.81

The objective of the present study was to evaluate a favourable interaction between phosphorus and salinity in order to enhance salt tolerance of pea crop using radiotracer techniques.

2 Materials and methods

In order to achieve the desired objectives, a green house experiment was conducted on a sandy soil. The bulk soil sample was air dried, passed through a 2 mm sieve and mixed thoroughly. The physico-chemical properties of the experimental soil were determined employing standard procedures (Anon, 1968 and Jackson, 1967) and are listed in **table 1**.

2.1 Preparation of saline soils

In order to achieve desired levels (SL: 4, 6 and 8 dSm^{-1}) and types (ST: $Cl:SO_4$ = 70:30 and 30:70) of salinity, calculated amounts (on equivalent basis) of Cl and SO_4 salts of Na, Ca and Mg were added in the soil. At equilibrium the saturated extract was analysed for its salt content by measuring the electrical conductivity EC_e (Anon, 1968) and osmotic potential. The total amounts of the salts added and exact values of EC_e and osmotic potential obtained are presented **in table 2**.

2.2 Layout

Polyethylene lined earthen pots were filled with 5 kg soil. Phosphorus as $NH_4H_2PO_4$ was applied @ 0, 30, 60 and 90 mg P kg^{-1} soil. Before its application it was tagged with carrier free ^{32}P (@ 0.30 mci g^{-1} P). Other nutrients such as N, K, Cu, Zn Cu, Mn and Fe were applied @ 40.6, 25.0, 2.5, 5.0, 5.0 and 10.0 mg kg^{-1} soil, respectively as a basal dose. In order to make the system homogeneous; these contents were thoroughly mixed. At a moisture content of field capacity, 10 seeds of pea (cv. HFP - 8712) were sown at a uni-

Table 2: Amount and proportion of different ions added to the soil to attain desired EC_e levels

Desired EC_e level (dSm^{-1})	Total salt added (meq L^{-1})	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	Obtained EC_e levels (dSm^{-1})	Osmotic potential (bars)
		(meq L^{-1})						
				Cl-dominated (Cl:SO_4 = 70:30)				
Non-saline	0	00.00	00.00	00.00	00.00	00.00	1.66	-0.50
4	50	25.00	6.25	18.75	35.00	15.00	4.14	-1.23
6	72	36.00	9.00	27.00	50.40	21.60	6.12	-2.78
8	105	52.50	13.13	39.37	73.50	31.50	8.10	-3.97
				SO_4-dominated (Cl:SO_4 = 30:70)				
Non-saline	0	00.00	00.00	00.00	00.00	00.00	1.66	-0.50
4	60	30.00	7.50	22.50	18.00	42.00	3.96	-1.09
6	90	45.00	11.25	33.75	27.00	63.00	6.00	-2.64
8	125	62.00	15.63	46.87	37.00	87.50	7.80	-3.89

form depth of 2 cm and after establishment, in total 4 plants were retained. A hollow plastic feeder tube (1.5 cm diameter) was embedded in the centre of the pot to a depth of 15 cm. The plants were irrigated with deionised water alternatively at surface and subsurface (through tube) as and when required. This irrigation strategy ensures free movement of the salts in the system and prevents an accumulation at the bottom. All necessary agronomic practices were followed during the course of experiment. The crop was harvested at maturity. The plants were washed sequentially with dilute HCl, tap water and finally with distilled water. After soaking the extra water, the samples were separated into different parts. After oven drying, the samples were weighed and ground in mill to a particle size of <2µm. The samples were analysed for P (John, 1970), S (Chesnin and Yein, 1950), Cl (Chhabra et al. 1976), Ca and Mg (versenate titration using EBT as indicator) and Na and K (flame emission spectrophotometer). Radio-assay was carried out on liquid scintillation counter (LS-1000 C Beckman, USA) using POP and POPOP as scintillators. The efficiency of added P was calculated according to the method of Mackenzie and Dean (1948). The experiment was carried out in a completely randomised block design with three replicates and the data were analysed calculating the least significant differences (LSD).

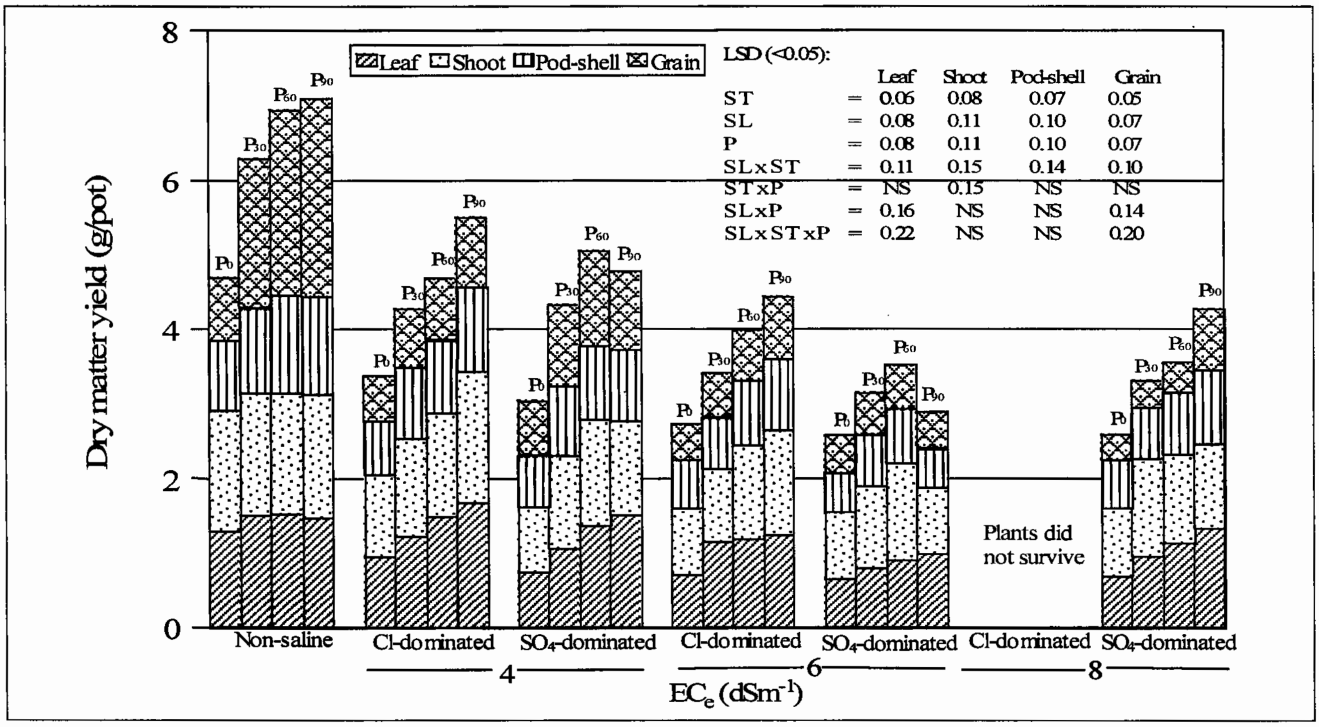

Fig. 1: Effect of P on yield of different plant parts of pea crop at various typres (ST) and levels (SL) of salinity

3 Results and discussion

3.1 Biomass/yield

Figure 1 depicts the influence of P application on total biomass production of the pea crop and its different plants parts in non-saline as well as in saline soils dominated by Cl and SO_4 ions. The highest biomass production was observed under non-saline conditions and it decreased with increase in salinity levels in both Cl and SO_4-dominated types. The average biomass, irrespective of P application, decreased by 28.6 and 41.3 per cent in Cl-dominated and 31.0 and 51.4 per cent in SO_4-dominated salinity at 4 and 6 dSm^{-1} level, respectively, if compared to the non-saline soil. Thus it can be inferred that SO_4-salinity was more deleterious than Cl-salinity for biomass production at low and moderate levels. But interestingly, at 8 dSm^{-1} the crop died a month after germination in Cl-dominated salinity, whereas, in SO_4-dominated salinity at this level, the crop not only did survive but statistically comparable yields were obtained to its preceding conductivity level. Manchanda et al. (1991) also observed that chickpea did not survive in Cl-dominated salinity at 5.1 dSm^{-1}, whereas, in SO_4-dominated, the crop yielded about 100 per cent more grain at 5.4 dSm^{-1} salinity to that of control. Contrary to our results, Mor and Manchanda (1992) and Yadav and Yadav (1998) observed higher yields of pea crop under SO_4-dominated than Cl-dominated salinity which could be due to different cultivars used in these studies. The decrease in the biomass with increasing salinity was due to the presence of more salts in the growth medium that might have caused more absorption of salts by the crop and thus decreased crop yield. Dahiya and Singh (1976), Hasson-Porath et al. (1983) Mor and Manchanda (1992) and Yadav and Yadav (1998) also reported a decrease in yield of pea as an effect of salinity.

The application of P enhanced the total biomass at all levels in both types of salinity. In non-saline soil, the added P did not influence the leaf shoot and pod husk but increased grain yield. It could be due to bolder size (higher thousand grain weight) of grain. The type of salinity greatly influenced the response of pea to P application. At 4 and 6 dSm^{-1} Cl-dominated EC_e, addition of every successive dose of P resulted in continuous increase in the biomass. The yield increased by 27, 39 and 63 per cent at 4 dSm^{-1} and 25, 46 and 67 per cent at 6 dSm^{-1} with the addition of 30, 60 and 90 mg P kg^{-1} soil, respectively. It is also evident that at both the levels of salinity in this type, there was an increase in biomass of all plant parts up to 90 mg P kg^{-1} soil level.

Whereas, in SO_4-dominated salinity at 4 and 6 dS m^{-1} level, the biomass increased only up to 60 mg P kg^{-1} soil and decreased at 90 mg P kg^{-1} soil. Moreover, in SO_4-dominated salinity, there was only a slight increase in grain yield with application of P. This kind of crop behaviour indicates that pea takes up higher amounts of P under Cl-dominated than SO_4-dominated salinity in order to enhance its tolerance against Cl-toxicity. Yadav and Yadav (1998) also noted higher response of pea to added P under Cl salinity than SO_4. This hypothesis has been further explained and varified by P utilisation pattern (see **table 4**). Several reports (Dravid, 1991, Mor and Manchanda, 1992 and Yadav and Yadav, 1998) have documented the increase in yield of pea crop as a function of P in saline soils.

Plotting the total biomass production against the osmotic potential of the saturated extract of saline soils of both types, it becomes clear that the decrease in yield is most likely related to the osmotic effect up to -1.0 bar (**fig. 2**). Further decreasing osmotic potentials are, however, not related to decrease in crop productivity independent of P levels. The results further reveal that the differences in the osmotic potential of -0.08 (between -3.89 and -3.97 bars) caused a high variation in crop yield. In Cl-dominated (8 dSm^{-1}) salinity at -3.97 bars) the plant could not survive, whereas, at same salinity level (-3.89 bars) there was about 12.8 per cent higher yield in SO_4-dominated salinity as compared to its preceding level of salinity. Therefore, it can be concluded that effect of salinity on the growth of the crop is ion-specific rather than dependent on the osmotic potential, particularly at higher EC_e levels. The biomass reduction up to -1.0 bar may be possibly due to the internal osmotic adjustment process of the plant cell which is not

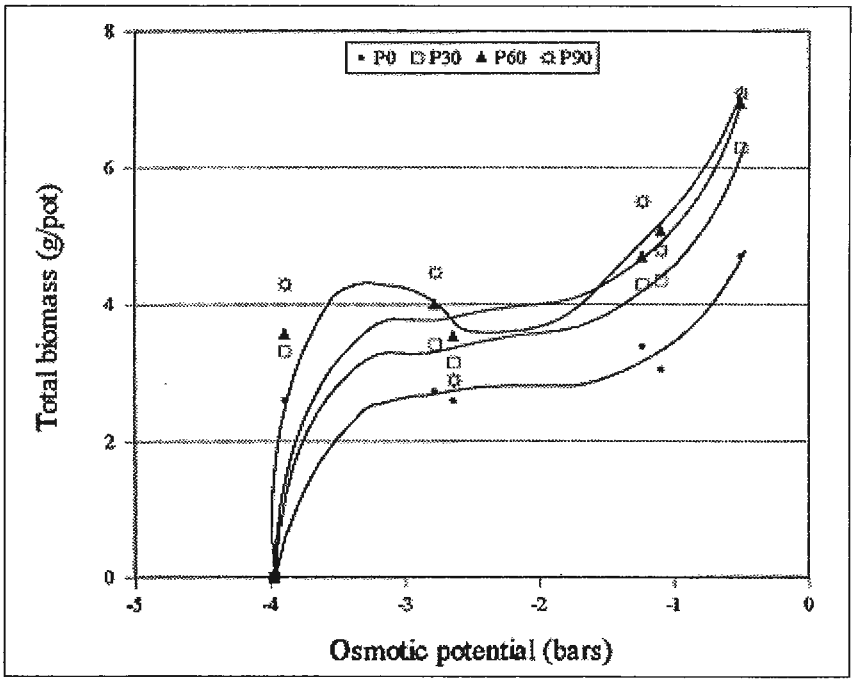

Fig. 2: Total biomass production of pea as influenced by P levels and osmotic potential

Table 3: Effect of P levels on P content (%) of different plant parts of pea crop at various levels and type of salinity

Added P (mg kg^{-1})	EC_e (dSm^{-1})	Cl-dominated			SO$_4$-dominated			
	1.66	4	6	Mean	4	6	8	Mean
				Leaf				
0	0.29	0.58	0.65	0.51	0.56	0.67	0.69	0.55
30	0.34	0.73	0.78	0.62	0.66	0.85	0.86	0.67
60	0.38	0.78	0.83	0.68	0.68	0.86	0.90	0.70
90	0.59	0.91	0.98	0.83	0.84	0.91	0.92	0.81
Mean	0.40	0.76	0.81	0.66	0.68	0.82	0.84	0.68
				Shoot				
0	0.48	0.56	0.62	0.55	0.52	0.54	0.64	0.54
30	0.61	0.65	0.71	0.66	0.60	0.63	0.75	0.65
60	0.62	0.78	0.79	0.73	0.67	0.77	0.79	0.71
90	0.70	0.85	0.92	0.82	0.75	0.87	0.96	0.82
Mean	0.60	0.71	0.76	0.69	0.63	0.70	0.78	0.68
				Pod-shell				
0	0.35	0.42	0.47	0.41	0.43	0.45	0.48	0.43
30	0.48	0.92	0.94	0.78	0.54	0.83	1.19	0.76
60	0.75	1.26	1.08	1.03	0.97	1.05	1.24	1.00
90	0.96	1.48	1.43	1.29	1.26	1.38	0.81	1.10
Mean	0.63	1.02	0.98	0.87	0.80	0.92	0.93	0.82
				Grain				
0	1.22	1.43	1.60	1.42	1.65	1.35	1.50	1.43
30	1.65	1.77	1.95	1.79	1.95	1.60	1.86	1.76
60	1.94	2.36	2.15	2.15	2.35	1.81	2.19	2.07
90	2.22	2.33	2.45	2.33	2.53	2.15	2.28	2.29
Mean	1.76	1.97	2.04	1.92	2.13	1.73	1.96	1.89

LSD (<0.05)		Leaf	Shoot	Pod-shell	Grain
Salinity type	=	0.03	0.01	0.05	0.04
Salinity level	=	0.04	0.02	0.07	0.05
P level	=	0.04	0.02	0.07	0.05
Salinity level x Salinity type	=	0.06	0.03	0.09	0.08
Salinity type x P level	=	NS	0.03	NS	0.08
Salinity level x P level	=	0.08	0.04	0.13	0.11
Salinity level x Salinity type x P level	=	NS	0.06	0.19	0.15

possible at higher osmotic potential. Cerda et al. (1982) concluded that yield reduction of pea was a function of osmotic potential of soil water in root zone (EC_e 2.5-10 dSm^{-1}) although specific ion effect also accounted for some degree of effect.

3.2 Elemental composition

3.2.1 P concentration

The data presented in **table 3** indicate that the P content of different plant parts increased significantly with increase in salinity of both types. Phosphorus concentration at 4 dSm^{-1} was significantly higher in Cl-dominated than SO$_4$-dominated in all plant parts except in grain where the trend was reverse. At 6 dSm^{-1} salinity level, the difference between Cl and SO$_4$-dominated salinities was non-significant in leaf and pod-shell but in shoot and grain portion it was higher in Cl-dominated as compared to SO$_4$-dominated salinity. Manchanda and Sharma (1989) and Mor and Manchanda (1992) also reported higher P content of chickpea and pea, respectively, under Cl-dominated than SO$_4$-dominated salinity. In non-saline soil, the P content increased significantly with increasing levels of P in pod-shell and grain but in shoot, the difference between 30 and 60 mg P kg^{-1} soil was not significant. With increasing salinity levels up to 6 dSm^{-1} in both types, the P content of the shoot, pod-shell and grain increased significantly with increasing levels of applied P. At 8 dSm^{-1} SO$_4$-dominated EC_e, the P content of shoot and grain increased significantly with increasing P levels but in shoot non-significant difference was observed between 30 and 60 mg P kg^{-1} soil whereas in case of pod-shell, significant increase was observed up to 30 mg P kg^{-1} soil level and was not affected at 60 mg P kg^{-1} soil as compared to other levels of P. The crop accumulated highest amount of P in grain, followed by pod-shell, leaf and shoot. The results are in contradiction with those of Malik et al. (1977); Georgiev and Spasenoveski (1977) who observed decrease in P content of leaf and stem of pea crop with increasing salinity. But Shah and Nadeem (1976), and Lal and Bhardwaj (1984) reported increasing P content of various plant parts of lentil and pea, respectively as the salinity level increase. In the present study, synergistic interactions between Cl and P was observed. It is in conformity with those of Grattan and Mass (1984, 1988) and Mor and Manchanda (1992) in soybean and pea, respectively.

3.2.2 P utilisation

The utilisation of P decreased significantly with increasing P levels in both types of salinity (**table 4**). The decrease in utilisation of P with increasing salinity compared to

Table 4: Effect of P application on total P utilisation (%) by pea crop at various levels and types salinity

Added P (mg kg^{-1})	EC_e (dSm^{-1})								
		Cl-dominated				SO_4-dominated			
	1.66	4	6	8	Mean	4	6	8	Mean
0	-	-	-	-	-	-	-	-	-
30	14.3	11.1	10.4	-	11.9	8.9	9.4	9.1	10.4
60	12.6	9.7	7.1	-	9.8	9.1	7.1	7.2	9.0
90	9.7	8.9	7.4	-	8.7	7.0	3.6	6.0	6.6
Mean	12.2	9.	8.3	-	10.1	8.3	6.7	7.4	8.7

LSD (<0.05)

Salinity type	=	0.05
Salinity level	=	0.72
P level	=	0.62
Salinity level x Salinity type	=	1.01
Salinity type x P level	=	0.88
Salinity level x P level	=	1.24
Salinity level x Salinity type x Salinity level x Salinity type	=	NS

the non-saline soil is related to the substantial decrease in biomass at higher EC_e levels. The lower P utilisation in SO_4-dominated salinity may be due to higher availability of native P in the presence of high concentration of SO_4^{2-} (Malik and Gupta, 1996). The P utilisation decreased with increasing P levels at all levels of both types of salinity. This decrease might be due to relatively more fixation of P by soil constituents. Singh et al. (1997) also observed decrease in P utilisation of pea with increase in P application rates. The data also indicate that total P utilisation by crop decreased significantly with increasing levels of salinity up to 6 dSm^{-1} level dominated by both types of anions. But in SO_4-dominated salinity, there was non-significant increase in P utilisation at 8 dSm^{-1} as compared to 6 dSm^{-1} salinity level. The utilisation of P was significantly higher in Cl-dominated than SO_4-dominated salinity at all applied P levels (except at 60 mg P kg^{-1} soil level where difference is very close to significance). On an average P utilisation was about 17 per cent higher under Cl-dominated salinity than in the SO_4-dominated treatment. This kind of behaviour is of particular interest in order to mitigating the deleterious effect of Cl ions, which are more harmful than SO_4. This phenomenon might have led to higher yields under Cl-dominated salinity.

3.2.3 S and Cl concentrations

The perusal of the data presented in **table 5** reveals that under Cl-dominance, the S concentration of leaf as well as of shoot remain least affected by increasing salinity levels whereas in case of pod-shell and grain the significant increase was observed only up to 4 dSm^{-1} level. On the other hand under SO_4-dominance, S concentration of all plant parts increased significantly with increasing salinity levels up to 6 dSm^{-1}. Regardless of salinity levels, increase in S concentration over control was observed highest in leaf (66 per cent), followed by shoot (39 per cent), followed by pod-shell (24 per cent) and lastly by grain (12 per cent). It is evident from these values that most of the S remains intact in the vegetative part of the crop and was not translocated in grains under the influence of the salinity. It is well demonstrated by the fact that even P application could hardly bring any substantial change in S content of grain (0 per cent under SO_4 and merely 11 per cent under Cl-stress) whereas S concentration of leaf increased by 59 and 34 percent, that of shoot by 31 and 26 per cent and that of pod-shell by 85 and 70 per cent by the application of P over control under C- and SO_4-dominated salinities. These values indicate that a strong synergistic interaction exists between P x S under Cl-stress and consequently minimising the Cl effect on plant growth. This could be assigned one of the possible factors for higher yields under this salinity regime. Our results are being supported by Manchanda et al. (1991) and Mor and Manchanda (1992) who also observed an increase in S concentration of pea under saline conditions. Mor and Manchanda (1992) also reported that magnitude was higher under SO_4-stress than Cl-stress when P was applied.

So far as Cl concentration is concerned, in all plant parts it increased significantly with increasing levels of both types of salinity. This phenomenon is because of proportional increase in the Cl content of soil with increasing salinity levels. It is also noticeable that at all salinity levels, the Cl content of all plant parts is significantly higher under Cl-dominance over SO_4, virtually due to higher Cl content of the growth medium. It seems very difficult to establish the influence of application of P on Cl content of various plant parts, as there is no statistical significant interaction between P levels x salinity type. But tendentially P application slightly increased the Cl concentration of all pant parts (ranging from 5 to 11 per cent as an average increase over control). Cerda et al. (1979), Siddque et al. (1983), Lal and Bhardwaj, Manchanda et al. (1991) and Mor and Manchanda (1992) also observed an increase in the Cl content of pea crop with increasing salinity levels. These results are contrary to those of Manchanda et al. (1982), Manchanda and Sharma (1982) for wheat and barley, respectively and that of Awad et al. (1990) for tomato who found decrease in Cl content under the influence of P. However, the results are in conformity with those of Grattan and Maas (1985, 1988) and Mor and Manchanda (1992) who observed that P application enhanced Cl absorption of soybean and pea crops, respectively. It appears that influence of P on the absorption and translocation of Cl varies from crop to crop and, therefore, can not be generalised.

3.2.4 Ca, Mg, Na and K concentrations

The data pertaining to concentration of these elements in various plant parts of pea crop are presented in **table 6**. The content of Ca, Mg and Na concentration of all plant parts increased while that of K decreased significantly with increasing EC_e levels of both salinity types. This increase may be attributed to the increasing concentration of these salts in soil system (**table 2**) while the decrease in the K concentration of different plant parts is caused by the competitive uptake of K and Na (Marschner et al., 1981; Sánchez-Raya and Delgado, 1996 and Savvas and Lenz, 1996). Malik et al. (1977) also observed an increase in Ca, Mg and Na concentration of pea crop grown on saline soils and also an increase in Mg and Na content of pea was reported by Mor and Manchanda (1992). The results are also in agreement with those of Malik et al. (1977), Siddique et al. (1983) and Lal and Bhardwaj (1984) who reported a decrease of the K content of pea under saline conditions while Cerda et al. (1979) found no change in K concentration of pea when salinity levels were increased from 1.4 to 13 dSm^{-1}. It is also apparent that the concentration of Ca and K in all plant parts is significantly higher under the influence of Cl stress as compared to SO_4-stress in most of the individual levels of salinity. This effect on K could be one of the possible interactive mechanisms to mitigate adverse effect of Cl

Table 5: Elemental composition (% S and Cl) of pea as affected by various levels of salinity and P in Cl and SO_4-dominated salinities

Treatments	EC_e type							
	Cl	SO_4	Cl	SO_4	Cl	SO_4	Cl	SO_4
	Leaf		Shoot		Pod-shell		Grain	
			S					
EC_e levels (dSm^{-1})								
1.66	0.69	0.69	0.36	0.36	0.29	0.29	0.17	0.17
4	0.71	1.12	0.39	0.59	0.38	0.40	0.20	0.20
6	0.72	1.37	0.39	0.58	0.43	0.54	0.20	0.22
8	-	1.42	-	0.60	-	0.62	-	0.18
Mean	0.70	1.15	0.38	0.53	0.37	0.46	0.19	0.19
P levels (mg kg^{-1})								
0	0.44	0.86	0.29	0.42	0.20	0.27	0.17	0.19
30	0.75	1.19	0.41	0.53	0.35	0.43	0.19	0.19
60	0.80	1.22	0.37	0.56	0.43	0.51	0.19	0.19
90	0.83	1.34	0.46	0.61	0.49	0.63	0.22	0.21
Mean	0.70	1.15	0.38	0.53	0.37	0.46	0.19	0.19
			Cl					
EC_e levels (dSm^{-1})								
1.66	1.39	1.39	2.15	2.15	1.62	1.62	0.95	0.95
4	4.44	3.97	5.76	4.61	2.49	1.94	1.54	1.31
6	6.73	5.33	7.05	6.12	4.51	3.11	3.45	2.69
8	-	5.72	-	6.26	-	3.75	-	3.43
Mean	4.18	4.15	4.99	4.79	2.87	2.60	1.98	2.09
P levels (mg kg^{-1})								
0	3.95	3.96	4.49	4.35	2.47	2.33	1.77	1.96
30	4.11	4.05	4.78	4.63	2.83	2.63	1.83	2.03
60	4.35	4.30	5.11	4.97	3.01	2.75	2.11	2.14
90	4.32	4.30	5.57	5.20	3.18	2.71	2.21	2.25
Mean	4.18	4.15	4.99	4.79	2.87	2.60	1.98	2.09

LSD (<0.05)	S				Cl			
	Leaf	Shoot	Pod-shell	Grain	Leaf	Shoot	Pod-shell	Grain
Salinity type	= 0.05	0.03	0.05	0.01	0.05	0.09	0.09	0.04
Salinity type x P level	= 0.09	NS	NS	NS	NS	NS	NS	NS
Salinity level x salinity type	= 0.09	0.08	0.09	0.01	0.09	0.19	0.19	0.07

salinity and hence higher yields under Cl-salinity compared with SO_4-salinity might have been obtained. But these results are contrary to those of M a n c h a n d a et al. (1991) and M o r and M a n c h a n d a (1992) who reported higher contents of K in shoots of pea crop under SO_4-salinity in comparison with than Cl-dominated. In case of Na and Mg, this trend was found reverse to K and Ca. The application of P has influenced the elemental composition of different

Table 6: Elemental composition (% Ca, Mg, Na and K) of pea as affected by various levels of salinity and P in Cl and SO_4-dominated salinities

Treatments	EC_e type							
	Leaf		Shoot		Pod-shell		Grain	
	Cl	SO_4	Cl	SO_4	Cl	SO_4	Cl	SO_4
EC_e levels (dSm-1)	Ca							
1.66	2.64	2.64	2.17	2.17	1.21	1.21	0.87	0.87
4	3.61	3.61	2.66	2.24	1.60	1.43	0.85	0.92
6	4.24	3.90	3.37	3.13	2.12	1.98	1.39	1.31
8	-	4.52	-	3.85	-	2.89	-	1.56
Mean	3.49	3.67	2.73	2.85	1.64	1.89	1.04	1.16
P levels (mg kg^{-1})								
0	3.95	4.13	3.10	3.21	1.85	2.09	1.15	1.25
30	3.65	3.91	2.86	2.96	1.67	1.91	1.07	1.21
60	3.32	3.48	2.62	2.75	1.61	1.82	1.00	1.11
90	3.06	3.14	2.35	2.46	1.46	1.70	0.93	1.09
Mean	3.49	3.67	2.73	2.85	1.64	1.89	1.04	1.16
EC_e levels (dSm^{-1})				Mg				
1.66	0.41	0.41	0.33	0.33	0.27	0.27	0.17	0.17
4	0.72	0.75	0.54	0.63	0.35	0.47	0.26	0.30
6	0.83	0.90	0.77	0.80	0.60	0.63	0.34	0.34
8	-	0.96	-	0.85	-	0.69	-	0.47
Mean	0.65	0.75	0.54	0.65	0.41	0.52	0.26	0.32
P levels (mg kg^{-1})								
0	0.50	0.61	0.40	0.53	0.33	0.47	0.23	0.28
30	0.61	0.74	0.51	0.62	0.35	0.50	0.25	0.31
60	0.72	0.84	0.60	0.69	0.45	0.52	0.28	0.35
90	0.77	0.82	0.67	0.76	0.50	0.58	0.28	0.35
Mean	0.65	0.75	0.54	0.65	0.41	0.52	0.26	0.32
EC_e levels (dSm^{-1})				Na				
1.66	0.13	0.13	0.24	0.24	0.10	0.10	0.12	0.12
4	0.64	0.74	1.40	1.58	0.45	0.51	0.43	0.45
6	1.25	1.36	2.15	2.34	1.20	1.08	0.35	0.38
8	-	1.35	-	2.61	-	1.29	-	0.56
Mean	0.67	0.91	1.27	1.69	0.58	0.74	0.30	0.39
P levels (mg kg^{-1})								
0	0.53	0.75	1.03	1.40	0.51	0.61	0.23	0.33
30	0.63	0.85	1.20	1.59	0.55	0.70	0.26	0.34
60	0.73	0.96	1.36	1.81	0.60	0.79	0.32	0.39
90	0.81	1.03	1.48	1.96	0.67	0.87	0.36	0.46
Mean	0.67	0.91	1.27	1.69	0.58	0.74	0.30	0.39
EC_e levels (dSm^{-1})				K				
1.66	1.45	1.45	1.73	1.73	1.40	1.40	1.12	1.12
4	0.96	0.88	1.48	1.24	0.99	0.86	0.85	0.51
6	0.82	0.72	0.90	0.73	0.71	0.60	0.61	0.47
8	-	0.60	-	0.58	-	0.38	-	0.33
Mean	1.08	0.91	1.37	1.06	1.03	0.81	0.86	0.61
P levels (mg kg^{-1})								
0	1.05	0.88	1.21	1.00	0.88	0.68	0.67	0.48
30	1.06	0.91	1.33	1.02	0.98	0.77	0.82	0.57
60	1.10	0.92	1.45	1.09	1.11	0.85	0.96	0.67
90	1.10	0.94	1.50	1.16	1.16	0.94	1.00	0.72
Mean	1.08	0.91	1.37	1.06	1.03	0.81	0.86	0.61

LSD (<0.05)	Ca				Mg			
	Leaf	Shoot	Pod-shell	Grain	Leaf	Shoot	Pod-shell	Grain
Salinity type	= 0.09	0.03	0.03	0.02	0.02	0.02	0.02	0.01
Salinity type x P level	= 0.18	0.07	NS	NS	0.03	NS	NS	0.01
Salinity level x salinity type	= 0.18	0.07	0.06	0.04	0.03	0.03	0.05	0.01
	Na				K			
Salinity type	= 0.02	0.05	0.03	0.01	0.02	0.02	0.02	0.02
Salinity type x P level	= NS	0.10	0.06	0.02	NS	0.04	NS	NS
Salinity level x salinity type	= 0.04	0.10	0.06	0.02	0.03	0.04	0.04	0.04

plant parts of pea crop in a considerable manner. The leaf and shoot concentration of Ca decreased significantly with increasing EC_e levels. This could be due to lesser availability of Ca due to formation of $Ca_3(PO_4)_2$. With regard to Na and Mg, increasing trend in their concentrations was observed. The application of P under both types of salinity affected the K concentration of shoot only and the interaction between P levels x salinity type for other plant parts were found non-significant. The K concentration of pea shoot increased significantly with increasing P levels under Cl-salinity whereas under SO_4-salinity such increases were obtained at 60 mg P kg^{-1} soil.

4 Summary and conclusion

Salinisation is the process whereby the concentration of total dissolved solids in water and soil is increased due to natural or human induced processes and is a major threat to the world's land and water resources particularly in arid and semi-arid regions where lack of rainfall and high evaporation rates aggravate the problem. One of the conventional approach to control the salinity has been to flush out the salts from the effective root zone. But this practice is no longer in use because of non-availability of fresh water in large scale for this purpose. Phosphorus has been recognised as a plant nutrient, which mitigates the salinity hazard, and the extent of its use/uptake has been indicative to cope up the salinity. It is in this context, a screen house experiment was conducted on saline soils (EC_e 1.66, 4, 6 and 8 dSm^{-1}) of different anion dominance ($Cl:SO_4$ = 70:30 and $Cl:SO_4$ = 30:70) taking pea as a test crop. The crop was fertilised with radioactive P (^{32}P) @ 0, 30, 60 and 90 mg P kg^{-1} soil. The adverse effect of the salinity can be judged from the reduction in crop yield. Contrary to many reports, our crop synthesised higher biomass under Cl-dominated than SO_4-dominated salinity at moderate and lower levels. The higher yields under this type can partially be justified by higher uptake of P and therefore, higher P utilisation was experienced to meet this requirement. At higher level (8 dSm^{-1}), Cl was more harmful which virtually killed one-month-old plants. It is also established that initial reduction in biomass was governed by osmotic potential of lower level (-1.0 bar) and further reduction at higher level of salinity was exclusively a specific ion effect. There exist a positive interaction between P and other elements like S, Mg and K which contribute to salt tolerance to some extent. However, the contribution of other processes such as compartmentation or osmotic adjustment for salt tolerance have not been investigated but are of vital interest for verification of causal interactions.

Steigerung der Salztoleranz von Erbsen durch Phosphatdüngung - ein Tracerversuch

Versalzung ist ein Prozeß, bei dem die Konzentration an gelösten Salzen im Wasser und im Boden aufgrund natürlicher oder anthropogen beeinflußter Prozesse ansteigt und ist insbesondere unter ariden und semiariden Bedingungen, d. h. bei nur geringen Niederschlagsmengen und einer hohen Evapotranspirationsrate, eine der größten Bedrohungen von Land- und Wasserressourcen.

Eine der gebräuchlichsten Methode , die Versalzung zu kontrollieren, war die Auswaschung der Salze aus dem durchwurzelten Bodenraum. Aufgrund des hohen Wasseraufwandes wird dieses Verfahren nicht mehr angewendet. Phosphor ist ein essentieller Pflanzennährstoff, welcher dem Salzstreß der Pflanzen direkt entgegenwirkt. Eine erhöhte Phosphataufnahme der Pflanzen senkt hierbei den Salzstreß. In einem Gewächshausversuch zu Erbsen (*Pisum sativum* L.) wurde deren Salzempfindlichkeit auf verschiedenen Böden (Ec_e 1.66, 4, 8 dSm^{-1}) und in Abhängigkeit verschiedener Anionenverhältnisse ($Cl:SO_4$ = 70:30 und $Cl:SO_4$ = 30:70) getestet. Darüber hinaus wurden insgesamt 0, 30, 60 und 90 mg P kg^{-1} Boden in Form von radioaktiv markiertem Phosphat zugeführt. Die Ergebnisse des Versuches können wie folgt zusammengefaßt werden:

- Mit zunehmendem Salzstreß sank der Ertrag.
- Im Gegensatz zu anderen Studien konnten bei niedrigem bzw. mäßigem Salzstreß höhere Erträge bei den Varianten mit höherem Cl-Anteil realisiert werden, was auf die signifikant höhere Phosphataufnahme im Vergleich zur Sulfat-Variante zurückgeführt werden kann.
- Bei starkem Salzstreß (8 dSm^{-1}) führte jedoch ein höherer Cl-Anteil nach einem Monat zum Absterben der Pflanzen.
- Bei niedrigem Salzstreß (-1.0 bar) stand der Rückgang an Biomasseproduktion in direktem Zusammenhang mit dem osmotischen Potential, während bei hohem Salzstreß zusätzliche Ertragsrückgänge auf spezielle Ioneneffekte zurückgeführt werden konnten.

Der Beitrag anderer Prozesse an der Ausprägung der Salzresistenz - wie z. B. Kompartimentierung oder osmotische Anpassung - waren nicht Gegenstand der vorliegenden Untersuchungen, sind jedoch von hervorragender Bedeutung zur Klärung kausaler Zusammenhänge.

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Authors:

Malik, Raj Singh, Institute of Crop and Grassland Science of the Federal Agricultural Research Centre (FAL); Head: PD Dr. Jörg Michael Greef;
Gupta, Anand Prakash, Department of Soil Science, HAU-Hissr, 12004, India;
Haneklaus, Silvia, Institute of Plant Nutrition and Soil Science of the Federal Agricultural Research Centre (FAL); Head. Prof. Dr. Dr. Ewald Schnug;
El Bassam, Nasir, Institute of Crop and Grassland Science of the Federal Agricultural Research Centre (FAL); Head: PD Dr. Jörg Michael Greef.