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Influence of fluoride and phosphorous on growth, yield and mineral composition of barley grown in soils of varied sodicity

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Abstract
Fluoride (F) is known to stimulate growth of many plant species but when absorbed in excessive amount is likely to be toxic to plants, animals and human beings. A screen house experiment was conducted in a completely randomized design to investigate the effect of varying levels of fluoride (0, 40, 80 and 160 mg/kg soil) and phosphorus (0, 12.5, 25 and 50 mg/kg soil) at two ESP levels (6.2 and 27.1) replicated thrice on the growth, yield and mineral composition of barley. The results revealed that increasing F concentration decreased growth parameters and dry matter yield especially at high ESP; however, application of phosphorous (P) increased growth and yield. Fluoride and P interacted significantly in affecting dry matter yield and mineral composition and adverse effect of added F was neutralized by higher application of P. Fluoride concentration in grain and straw was greater in high ESP soil as compared to low ESP soil because of the higher solubility of added F at high ESP. application of P decreased the F content of the plant thus aided in reducing the toxic effect of F on growth. The application of fluoride resulted in decreased concentration of K and Ca and increased concentration of Na in both the grain and straw and reverse was the case for P. The application of F and P resulted in decreased concentration of micronutrients i.e. Zn, Cu, Mn and Fe in both the grain and straw.

Keywords: Chemical composition, fluoride, phosphorous, ESP, yield

Introduction
Fluoride (F^-) is an anion of fluorine having small radius with remarkable tendency to act as a ligand and easily combines with numerous organic and inorganic substances in soil, rocks, air, plants and animals (Habuda-Stanic *et al*., 2014; Barnwal *et al*., 2017) [1, 2]. Fluorine is the 13th most abundant element representing about 0.3 g kg^{-1} of the earth's crust. In India, 2% of the geographical area is occupied by salt affected soils especially in arid and semi-arid regions and coastal regions (Mandal and Sharma, 2010; Bhat *et al*., 2017) [3, 4] ; out of which 3.79 and 2.95 m ha are sodic and saline soils, respectively (Rani *et al*., 2019) [5]. Gypsum is used as an amendment for the amelioration of sodic soils in Indo-Gangetic plains. Moreover, phospho-gypsum a by-product of different phosphatic fertilizers is extensively used in the reclamation of sodic soils because it contains more than 90% calcium sulphate. However, it has higher fluoride content varying from 2-4 per cent (Singh *et al*., 1979a; Barnwal *et al*., 2017) [6, 2]. Phosphate fertilizers and F-containing pesticides are additional sources releasing F into the environment (Czarnowski *et al*., 1994; Cronin *et al*., 2000) [7, 8]. The sources of fluoride for plant uptake are air, soil and water (Weinstein, 1977; Davison, 1982) [9, 10]. Plants tend to be more susceptible to fluoride injury from soil than from the atmosphere. In the air fluorides can occur in gaseous (principally HF, SiF_4) and particulate forms. Both forms are deposited on leaf surfaces but gaseous fluoride is also taken up through stomata and is extremely phytotoxic (Weinstein, 1977) [9]. The main natural sources of fluoride in soils are apatite, cryolite, fluorite or fluorospar and topaz (Pickering, 1985) [11]. Fluoride is emitted mainly from mining and workings, fertilizer and other chemical industry and metal manufacturing. In addition to this, there is consensus that soils of high pH probably contain toxic quantity of water-soluble F which may badly alter plant growth and tissue composition (Larsen and Widdowson, 1971; Singh *et al*., 1979a) [12, 6].

Fluoride is known to stimulate growth of many plant species but when absorbed in excessive amount is likely to be toxic to plants, animals and human beings (Singh *et al*., 1962) [13]. Higher content of fluoride results in varied mineral composition in plants that is vital for different physiological and physiological and biochemical reactions (Elloumi *et al*., 2005) [14]. These reactions are hindered by the inhibition of enzymes or interference with membrane integrity via fluoride precipitation with other minerals (Stevens *et al*., 1998; Gadi *et al*., 2012) [15, 16]. Certain physiological processes like germination, early root and shoot growth, chlorosis, leaf tip burn and leaf necrosis are significantly affected by F (Weinstein and Davison, 2004; Saini *et al*., 2013) [17, 18]. The significance of seed germination and plant growth is extensively documented and the effects of F toxicity have been ascertained by various researchers (Stanley *et al*., 2002; Sabal *et al*., 2006; Bhargava and Bhardwaj, 2010; Chakrabarti and Patra, 2013; Brahmbhatt and Patel, 2013) [19, 20, 21, 22, 23]. The excessive amount of fluoride is governed by its concentration in equilibrium solution (Leon *et al*., 1948; Singh *et al*., 1979a; Barnwal *et al*., 2017) [24, 6, 2]. The absorption of fluoride by plants in excessive amounts results in yield reduction. The fluoride concentration in equilibrium solution is governed by a number of factors such as pH, organic carbon, ESP, calcium carbonate, texture, parent material, quality of irrigation water, fertility status and addition of fluoride bearing compounds. Response of fluoride depends upon some factors such as dose, duration of exposure, age and genotypes of plants. Fluoride uptake by plants depends upon several factors, the most important of which are plant species and fluoride concentration in the soil solution. The interaction between F and P was investigated by various researchers in soils of diverse reaction (pH); for instance Prince *et al*. (1949) [25] evinced that toxicity of F in buckwheat was reduced by increased rate of P application. Similarly, Singh *et al*. (1979a, b in wheat and rice, respectively) [6, 26], Elrashidi *et al*. (1998) [27] in barley and Bhardwaj (2006) [28] in wheat studied the interaction of F and P. In view of the fact that meagre work has been done on the interactive effect of fluoride and phosphorus on barley under sodic conditions, therefore, this study was planned to evaluate how the interaction between fluoride and phosphorous affect growth, yield and mineral composition of barley in soils of varying sodicity.

Materials and Methods

A pot experiment was conducted in screen house of the Department of Soil Science, CCS Haryana Agricultural University, Hisar located at 29° 05' N latitude 75° 38' E longitude and an altitude of 222 m above mean sea level. The climate of the study area is semi-arid subtropical showing hot summers and cold winters with maximum temperature about 48°C and minimum temperature almost zero and total annual rainfall is 450 mm approximately occurring mostly during the months of July to September. Before the start of the experiment the soil was analysed for different physico-chemical properties (Table 1). Bulk surface soil sample (0-15 cm) was collected from village Balsamand (Balsamand Series), District Hisar. The soil was air-dried, ground and passed through 2 mm sieve.

The experiment was laid out in factorial completely randomized design (CRD) having three replications with four levels each of fluoride (control, 40, 80 and 160 mg/kg) and phosphorus (control, 12.5, 25 and 50 mg/kg) and two levels of ESP (6.2 and 27.1). The soil was filled in polythene lined earthen pots of 5 kg capacity. The required volume of sodium fluoride (NaF) and potassium dihydrogen phosphate (KH_2PO_4) solutions were added to obtain fluoride and phosphorus levels of (0, 40, 80 and 160 mg/kg) and (0, 12.5, 25 and 50 mg/kg), respectively. Nitrogen was applied through urea in three split doses i.e. 90 mg/kg at sowing and remaining was top dressed at the rate of 30 mg/kg at 35 and 60 days after sowing. In order to compensate the potassium supplied by KH_2PO_4, a part of K was applied through muriate of potash (KCl). Sodium (Na) was supplied through the varying levels of NaF and remaining Na was compensated through NaCl. Ten seeds of barley (cv. BH-902) were sown in each pot and after seven days were thinned to six plants per pot. The irrigation was done strictly with distilled water as and when required. The crop was harvested at maturity and the plants were partitioned into straw and ear heads. Plant height from ground surface to the top of spike and spike length in centimetres were measured at physiological maturity. Spike length was measured without awn. The grains were threshed and then both the grain and straw were stored separately. Chlorophyll was extracted by the method described by Hiscox and Israelstam (1979) [29] using dimethyl sulphoxide (DMSO) by the spectrophotometer. The harvested plants were washed with deionized water, oven dried (65°C), weighed for drymatter yield and ground through Wiley mill for chemical analysis. Plant samples were digested using HNO_3 and $HClO_4$ and H_2SO_4 and $HClO_4$ (3:1) mixture and analysed for various elements. Calcium was determined by atomic absorption spectrophotometer and Na and K by flame photometer. Fluoride was determined by using ion-selective electrode (Model-Orion 90-01) as indicated by Villa (1979) [30] and analysed by specific ion meter. Phosphorous, N and S were determined by vanadomolbydate yellow colour method, microKjeldahl method, barium sulphate turbidimetry method, respectively (Jackson, 1973) [31]. Micronutrients content (Zn, Cu, Mn and Fe) was determined using atomic absorption spectrophotometer (Isaac and Kerber 1971 [32].

All the data were analysed using completely randomized block design for analysis of variance (ANOVA) and differences among treatments were compared at $\alpha \leq 0.05$ using the IRRISTAT data analysis package (IRRI) [33].

Table 1: Physico-chemical characteristics of the soil used for screen house experiment

Characteristics	Content
Mechanical composition (%)	
Sand	71.70
Silt	18.96
Clay	9.34
Texture	Sandy loam
pH(1:2)	8.18
Electrical conductivity(1:2) [dS/m]	0.95
Cation exchange capacity(CEC) [cmol(p+)/kg]	10
Saturation percentage	38
Organic carbon [%]	0.42
Olsen' s extractable-P [mg/kg soil]	3.45
Water extractable-F [mg/kg soil]	4.25
Exchangeable sodium percentage	6.2

Results and Discussion

Growth parameters

Germination percentage

The germination percentage of barley varied from 70 to 100 per cent in soil at ESP 6.2 on 10 days after sowing and 60 to 80 per cent on 16 days after sowing in soil at ESP 27.1

indicating that the effect of fluoride was more prominent in soils of higher ESP. The number of days taken for germination also increased at ESP 27.1 (Data not shown). Germination of barley seeds decreased with the application of applied F in soil and increased with increasing levels of P in soil. The maximum delay in germination was observed at ESP 27.1 and F level of 160 mg/kg compared to normal soil which may be ascribed to significant changes in moisture percentage during the germination period, since, availability of moisture is one of the most important factors for germination especially at its initiation. The cells have to be turgid before they could extend or expand and only then the emergence takes place. Since, the moisture content and penetration is very low in sodic soils; so germination is highly inhibited and the days taken for germination is also increased. Bhargava and Bhardwaj (2010) [21] observed maximum phytotoxicity on percentage germination of wheat at 20mg/L NaF concentration (88%). Chakrabarti and Patra (2013) [22] reported that the addition of NaF decreased 50% seed germination in paddy. Brahmbhatt and Patel (2013) [23] noticed that addition of NaF delayed germination in alfalfa. Kaur and Duffus (1989) [34] reported that the effects of NaF on germination of barley are a consequence of fluoride toxicity and that of sodium. During germination the seedling mostly depends on stored food than on external nutrient, therefore, no significant variation was noticed on germination percentage by fertilizer application (Tigre *et al*., 2014) [35].

Plant height at maturity

The data pertaining to plant height of barley at maturity in relation to sodicity is presented in Table 2. Plant height decreased significantly with increasing F levels at both ESP levels. The decrease in mean plant height was 6.9 per cent and 6.4 per cent at ESP levels of 6.2 and 27.1, respectively with increasing F levels from 0 to 160 mg/kg soil. The mean plant height increased significantly with increasing application of P from 0 to 50 mg/kg soil irrespective of the levels of sodicity in the absence of applied F which clearly indicates that the application of P mitigated the harmful effect of F as the plant height increased with the application of P even at the highest level of F as compared to control. The per cent increase in plant height was 21.6 and 26.4 at ESP 6.2 and 27.1, respectively. Singh *et al*. (2001) [36] observed that different concentration of sodium fluoride decreased plant height of wheat. Singh *et al*. (2013) [37] studied the effect of various concentrations of NaF kg^{-1} soil on growth parameters and reported that the sodium fluoride reduced plant height with maximum reduction at 400 mg NaF kg^{-1} soil as compared to control. The increase in plant height by P application may be ascribed to enhanced photosynthetic rate thereby encouraging the vegetative growth (El-Habbasha *et al*., 2007; Irfan *et al*., 2019) [38, 39].

Table 2: Effect of phosphorus and fluoride on plant height (cm) of barley at maturity in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	F added (mg kg^{-1})					P added (mg kg^{-1})	F added (mg kg^{-1})				
	0	40	80	160	Mean		0	40	80	160	Mean
0	46.5	44.4	45.0	44.2	45.0	0	42.7	41.3	41.8	40.5	41.6
12.5	48.0	45.8	47.3	45.7	46.7	12.5	46.2	44.6	43.8	43.3	44.5
25	51.1	48.8	49.1	47.6	49.2	25	47.7	48.8	46.3	46.3	47.3
50	56.2	58.8	53.2	50.5	54.7	50	54.8	55.4	51.3	48.9	52.6
Mean	50.5	49.5	48.7	47.0		Mean	47.9	47.5	45.8	44.8	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 2.2; F = 2.2; P X F = NS						P = 2.1; F = 2.1; P X F = NS					

Total chlorophyll content

The data pertaining to total chlorophyll content of barley leaves is presented in Table 3. Chlorophyll content decreased significantly from 0.857 to 0.805 mg/g at ESP level of 6.2 and from 0.837 to 0.779 mg/g at ESP 27.1 when F level was increased from 0 to 160 mg/kg soil. The percent decrease in mean chlorophyll content was 6.0 and 6.9 at ESP 6.2 and 27.1, respectively. The decrease in total chlorophyll content may be attributed to the breakdown of chlorophyll under stress or due to inhibition of chlorophyll biosynthesis. Magnesium is a central component of chlorophyll and it traps fluoride as MgF_2 in a detoxification mechanism and this may be the cause of decrease in the chlorophyll content in the plants. Decrease in chlorophyll content may also be due to the disruption of chloroplast membranes. The biochemical basis for this effect might be due to the inhibition of the incorporation of ɤ-aminolevulinic acid into the chlorophyll synthetic pathway by fluoride (Wallis *et al*., 1974; Kaur and Duffus, 1989) [40, 34]. Bhargava and Bhardwaj (2010) [21] reported that total chlorophyll concentration in wheat was 0.074 mg/g at 20mg/L NaF which reduced by 27.45% compared to control (0.102 mg/g). Chakrabarti and Patra (2013) [22] also ascertained that the total chlorophyll of the leaves decreased with increasing NaF concentration in paddy. The total chlorophyll content increased significantly from 0.805 to 0.864 and 0.777 to 0.831 mg/g with increasing levels of P from 0 to 50 mg/kg soil at ESP levels of 6.2 and 27.1, respectively. The percent increase in mean chlorophyll content was 7.3 and 6.9 at ESP 6.2 and 27.1, respectively with increasing P levels in soil from 0 to 50 mg/kg soil. Epie and Maral (2018) [41] stated that phosphorus application improved chlorophyll content in wheat.

Table 3: Effect of phosphorus and fluoride on chlorophyll content (mg g^{-1}) of barley leaves in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	F added (mg kg^{-1})					P added (mg kg^{-1})	F added (mg kg^{-1})				
	0	40	80	160	Mean		0	40	80	160	Mean
0	0.820	0.781	0.766	0.853	0.805	0	0.802	0.807	0.733	0.768	0.777
12.5	0.916	0.857	0.833	0.707	0.828	12.5	0.802	0.774	0.788	0.832	0.799
25	0.808	0.931	0.903	0.758	0.850	25	0.854	0.857	0.821	0.762	0.823
50	0.883	0.837	0.836	0.902	0.864	50	0.891	0.841	0.836	0.754	0.831
Mean	0.857	0.851	0.835	0.805		**Mean**	0.837	0.820	0.795	0.779	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.003; F = 0.003; P X F = 0.007						P = 0.005; F = 0.005; P X F = NS					

Spike length

The data pertaining to spike length of barley is presented in Table 4. The mean spike length decreased significantly from 6.3 to 5.6 cm at an ESP 6.2 and 5.6 to 4.9 cm at ESP 27.1 with increasing levels of F from 0 to 160 mg/kg soil. The mean spike length decreased by 11.1 per cent and 12.5 per cent at ESP levels of 6.2 and 27.1, respectively thereby indicating that the mean spike length decreased with increasing levels of F application irrespective of ESP levels. The mean spike length increased from 5.0 to 6.8 cm at an ESP level of 6.2 with increase in applied P level from 0 to 50 mg/kg soil, whereas at ESP 27.1 it increased from 4.6 to 5.9 cm with the same increasing levels of P in soil. The mean spike length increased to the tune of 36.0 and 28.0 per cent at ESP levels of 6.2 and 27.1, respectively when P level was increased from 0 to 50 mg/kg soil indicating that spike length increased at both the ESP levels with the increasing levels of P. The interaction of F and P was non-significant at both the levels of sodicity. The addition of increased levels of P increased spike length because phosphorus is a component of various cellular molecules like ATP, nucleic acids, phospholipids, and phosphorylated sugars, and therefore plays a critical role in carbon metabolism and thereby growth (Huang *et al*., 2008) [42]. Hussain *et al*. (2016) [43] also reported positive effect of P application on spike length in wheat.

Table 4: Spike length (cm) of barley as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	5.3	5.0	4.9	4.9	5.0	0	5.1	4.8	4.2	4.2	4.6
12.5	6.0	5.6	5.3	5.3	5.6	12.5	5.6	5.0	4.9	4.4	5.0
25	6.6	6.0	6.5	5.9	6.3	25	5.4	5.7	5.3	5.2	5.4
50	7.1	7.0	6.6	6.4	6.8	50	6.3	5.8	5.9	5.8	5.9
Mean	6.3	5.9	5.8	5.6		**Mean**	5.6	5.3	5.1	4.9	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.4; F = 0.4; P X F = NS						P = 0.3; F = 0.3; P X F = NS					

Number of grains per ear head

The data pertaining to the number of grains per ear head is presented in Table 5. The number of grains per ear head decreased from 27 to 20 per ear head and from 23 to 20 per ear head at ESP levels of 6.2 and 27.1, respectively with increasing levels of F in soil from 0 to 160 mg/kg soil. However, application of P had direct bearing on the number of grains per ear head. Number of grains increased from 21 to 28 and from 19 to 25 per ear head with increase in applied P levels from 0 to 50 mg/kg soil at ESP levels of 6.2 and 27.1, respectively. Abbas *et al.* (2016) [44] and Hussain *et al.* (2016) [43] stated that phosphorus application significantly improved number of grains per spike in barley and wheat, respectively.

Table 5: Number of grains per ear head in barley as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	21	22	21	20	21	0	19	21	19	17	19
12.5	24	23	24	19	22	12.5	23	18	20	19	20
25	27	25	23	19	24	25	24	24	19	19	22
50	33	31	25	21	28	50	26	24	26	22	25
Mean	27	25	23	20		Mean	23	22	21	20	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 2.5; F = 2.5; P X F = NS						P = 1.7; F = 1.7; P X F = NS					

Grain yield

The data pertaining to grain yield of barley is presented in Table 6. Grain yield decreased significantly from 10.73 to 9.58 g/pot with increasing F levels from 0 to 160 mg/kg soil at ESP of 6.2. The grain yield decreased by 8.2 per cent and 13.3 per cent when F was increased from 0 to 160 mg/kg soil in the absence of Pat ESP levels of 6.2 and 27.1, respectively. The effect of F on grain yield was more pronounced in soil of ESP 27.1 where the mean grain yield decreased from 9.05 to 7.61 g/pot with increase in F levels from 0 to 160 mg/ kg soil and the per cent reduction was 15.9 at F level of 160 mg/kg soil as compared to control. Grain yield decreased with increasing application of fluoride in the soil which might be due to the accumulation of F by plants in excessive amounts and resulting anionic and cationic imbalance in the plant tissues. Elrashidi *et al*. (1998) [27] reported significant negative effect of fluoride on dry matter of barley on acid and neutral soil and assigned this to accumulation of toxic amounts of F in soils, increasing the mobility of other toxic elements in soils (for instance Al) and the effect on nutrient balance in the plant.

The grain yield increased significantly from 8.16 to 12.35 g/pot with increasing levels of P from 0 to 50 mg/kg soil at ESP 6.2 and the per cent increase was 51.3 at P level of 50 mg/kg soil as compared to control whereas, the grain yield increased from 6.79 to 10.24 g/pot at ESP 27.1 with added P level of 50 mg/kg soil as compared to control and the per cent increase was 50.8 per cent which indicated that the grain yield decreased significantly with increasing ESP. The interaction of F and P was significant at both the levels of sodicity. The harmful effect of F may be mitigated by the application of phosphorus. In our experiment the soils were low in available P that may be the reason that dry matter yield increased with increasing levels of P. Singh *et al*. (1979a) [6] reported that fluorine uptake by plants increased linearly with increased water extractable fluorine in soils thereby resulted in significant reduction in wheat yield. Bhardwaj (2006) [28] ascertained that grain yield decreased with increasing levels of fluorine at maximum level of F (200 mg kg^{-1}) along with increasing ESP, however, with the application of P the yield increased. The higher P concentration is responsible for proper development of leaves as P plays a pivotal role in synthesis of sucrose and starch in photosynthesis thereby increasing dry matter yield (Cakmak *et al*., 1994; Gulmezoglu and Daghan, 2017) [45, 46].

Table 6: Effect of application of phosphorus and fluoride on grain yield (g pot^{-1}) of barley in relation to sodicity Straw yield

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	F added (mg kg^{-1})					P added (mg kg^{-1})	F added (mg kg^{-1})				
	0	40	80	160	Mean		0	40	80	160	Mean
0	8.68	8.33	7.98	7.65	8.16	0	7.21	6.96	6.71	6.25	6.79
12.5	9.67	9.52	9.09	8.75	9.26	12.5	8.01	7.95	7.56	6.98	7.63
25	11.66	11.03	10.71	10.09	10.87	25	9.83	8.95	8.53	7.96	8.82
50	12.91	12.52	12.15	11.85	12.35	50	11.15	10.69	9.85	9.25	10.24
Mean	10.73	10.35	9.98	9.78		Mean	9.05	8.64	8.16	7.61	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.35; F = 0.35; P X F = 0.70						P = 0.54; F = 0.54; P X F = 1.08					

The data pertaining to straw yield of barley is presented in Table 7 which revealed that straw yield decreased significantly with increasing levels of F from 0 to 160 mg/kg soil in absence of P. However, straw yield increased from 17.57 to 22.61 g/pot with increasing application of P from 0 to 50 mg/kg soil with no added fluoride in the soil. The straw yield decreased by 7.7 per cent when added F was increased from 0 to 160 mg/kg soil in the absence of Pat ESP level of 6.2 and the straw yield increased by 28.7 per cent with increasing levels of P from 0 to 50 mg/kg soil in absence of F. The straw yield was 16.40 g/pot at ESP 27.1 when there was no applied P and F in soil but it decreased to 15.65 g/pot with increasing levels of F from 0 to 160 mg/kg soil in absence of applied P to the soil. The detrimental effect of F on plant growth was more at 160 mg/kg soil. The results of are in agreement with those of Singh *et al*., (1979a) [6] who reported that the yield of wheat straw decreased linearly with increasing levels of fluoride in the soil. The adverse effect of added F was more marked in the soil of higher ESP. The higher reduction of yield at higher ESP may be due to accumulation of F by plants in toxic amounts and subsequent ionic imbalance within the plants. However, straw yield increased from 16.40 to 21.05 g/pot at ESP 27.1 with increasing application of P from 0 to 50 mg/kg soil with no added fluoride and straw yield increased by 28.4 per cent with increasing levels of P from 0 to 50 mg/kg soil in absence of F. Straw yield decreased significantly from 20.00 to 18.80 g/pot and 18.6 8 to 17.63 g/pot with increasing F levels from 0 to 160 mg/kg soil at an ESP level of 6.2 and 27.1, respectively. The decrease was 6.0 and 5.6 per cent at added F level of 160 mg/kg soil as compared to control. The per cent increase at P level of 50 mg/kg soil was 30.7 and 27.8 per cent at ESP level of 6.2 and 27.1, respectively as compared to control. The interaction of F and P was significant at ESP 6.2 and non-significant at ESP 27.1. The counteracting effect of applied P on the yield depression due to F application may be ascribed to the possible immobilization of added F resulting in the formation of relatively insoluble intermediate compounds of Ca, Mg and K or the competitive inhibition of P and F uptake by the plants. The precipitation of F as fluorapatite 3 [$Ca_3(PO_4)_2CaF_2$] is generally ruled out within short periods of its application in the soil (Jung, 1953; Sacharrer *et al*., 1953; MacIntire *et al*., 1942; Singh *et al*. 1979b) [47, 48, 49, 26].

Table 7: Effect of application of phosphorus and fluoride on straw yield (g pot^{-1}) of barley in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	F added (mg kg^{-1})					P added (mg kg^{-1})	F added (mg kg^{-1})				
	0	40	80	160	Mean		0	40	80	160	Mean
0	17.57	17.45	16.88	16.22	17.03	0	16.40	16.25	15.89	15.65	16.05
12.5	19.02	18.63	18.26	17.77	18.42	12.5	17.89	17.63	17.19	16.66	17.34
25	20.78	20.45	19.91	19.63	20.19	25	19.37	18.98	18.64	18.34	18.83
50	22.61	22.56	22.19	21.57	22.26	50	21.05	20.75	20.36	19.89	20.51
Mean	20.00	19.77	19.31	18.80		Mean	18.68	18.40	18.02	17.63	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.46; F = 0.46; P X F = 0.92						P = 0.52; F = 0.52; P X F = NS					

Chemical composition

Fluoride

Fluoride content in barley grain and straw increased significantly with increasing F and P levels in soil at both sodicity levels (Tables 8 and 9). The relative increase in F content at higher F applications was much larger at high ESP compared to low ESP. The higher solubility at high ESP is expected owing to higher pH at ESP 27.1. The reason may be the displacement of fluoride held on surface of minerals by hydroxyl ions (Larsen and Widdowson, 1971; Singh *et al*., 1979a) [12, 6]. The higher accumulation of F by plants grown in soils of high ESP may be ascribed to its higher extractability in sodic soils (Chhabra *et al*., 1980) [50]. The interaction between F and P was non-significant in grain and straw at both ESP levels except at 6.2 in case of grain. Elrashidi *et al*. (1998) [27] also reported that soil F addition and its interaction with P had highly significant effects on F uptake by barley plants. Stevens *et al*. (1998) [15] and Jha *et al*. (2008) [51] observed that when a high concentration of the fluoride is added to the soil or soil solution, pH becomes more alkaline which could increase the fluoride concentration in soil solution and more fluoride would be potentially available for uptake by the plant root.

Table 8: Effect of application of phosphorus and fluoride on fluoride concentration (mg kg^{-1}) in barley grain in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	1.02	1.21	1.33	1.76	1.33	0	1.56	1.71	1.96	2.21	1.86
12.5	1.41	1.56	1.71	1.83	1.63	12.5	1.71	1.92	2.18	2.31	2.03
25	1.53	1.77	1.92	2.08	1.83	25	2.02	2.18	2.44	2.59	2.31
50	1.79	1.92	2.24	2.49	2.11	50	2.38	2.45	2.57	2.71	2.53
Mean	1.44	1.62	1.80	2.04		Mean	1.92	2.07	2.29	2.45	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.10; F = 0.10; P X F = 0.21						P = 0.12; F = 0.12; P X F = NS					

Table 9: Effect of application of phosphorus and fluoride on fluoride concentration (mg kg^{-1}) in barley straw in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	7.96	13.34	20.26	41.08	20.66	0	14.86	21.38	23.18	41.58	25.25
12.5	8.12	13.62	20.34	42.61	21.17	12.5	14.95	21.96	23.85	42.98	25.93
25	8.37	13.95	20.53	43.81	21.67	25	15.31	22.65	24.34	43.94	26.56
50	8.66	14.22	20.89	45.18	22.24	50	15.66	22.43	24.94	44.65	26.92
Mean	8.28	13.78	20.51	43.17		Mean	15.20	22.10	24.08	43.29	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.48; F = 0.48; P X F = 0.96						P = 0.64; F = 0.64; P X F = NS					

Phosphorous

Phosphorus concentration in both grain and straw increased significantly with increasing application of P and decreased with increasing levels of F and sodicity in the soil (Tables 10 and 11). The increase in P concentration may be ascribed to the excessive presence of P in the soil solution and the decreased P concentration with increasing levels of F might be due to the formation of such compounds of fluoride and phosphorus which are not soluble and are not solubilized by root activity. The decreased P concentration with increasing level of sodicity and fluoride levels was also reported by Singh *et al.* (1979a) [6]. Phosphorous is crucial for growth of roots as root hairs are modified plant cells which significantly increase root surface area thereby enhance water and ion uptake (Bates and Lynch, 2000; Hussain *et al*., 2016) [52, 43]. Façanha and Okorokova-Façanha (2002) [53] reported that environmental pollution by fluorine and its interaction with aluminium may aggravate of the problem of phosphorus availability in the soils.

Table 10: Effect of application of phosphorus and fluoride on phosphorus concentration (%) in barley grain in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	0.31	0.29	0.27	0.25	0.28	0	0.24	0.23	0.23	0.22	0.23
12.5	0.34	0.32	0.31	0.26	0.31	12.5	0.32	0.28	0.27	0.24	0.28
25	0.37	0.35	0.32	0.31	0.34	25	0.33	0.31	0.31	0.28	0.31
50	0.38	0.38	0.37	0.34	0.37	50	0.36	0.34	0.34	0.33	0.34
Mean	0.35	0.34	0.32	0.29		**Mean**	0.31	0.29	0.29	0.27	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.01; F = 0.01; P X F = 0.02						P = 0.01; F = 0.01; P X F = 0.01					

Table 11: Effect of application of phosphorus and fluoride on phosphorus concentration (%) in barley straw in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	0.071	0.068	0.066	0.064	0.067	0	0.064	0.061	0.059	0.054	0.059
12.5	0.075	0.073	0.071	0.068	0.072	12.5	0.072	0.068	0.063	0.058	0.065
25	0.084	0.081	0.078	0.074	0.079	25	0.079	0.074	0.071	0.068	0.073
50	0.096	0.095	0.092	0.091	0.093	50	0.086	0.085	0.084	0.083	0.084
Mean	0.082	0.079	0.077	0.074		Mean	0.075	0.072	0.069	0.066	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.006; F = 0.006; P X F = NS						P = 0.007; F = 0.007; P X F = NS					

Nitrogen

Nitrogen concentration in both barley grain and straw exhibited no systematic trend with increase in levels of F in soil, however, increased with increase in levels of phosphorus at both sodicity levels which may be due to synergistic relationship between N and P (Tables 12 and 13). The reactions of plants to soil contamination with fluorine are complex and involve changes in many biochemical processes associated with content of nitrogen forms in the biomass of crops (Szostek and Ciećko, 2017) [54]. Abid *et al.* (2002) [55] reported that phosphorus application improves the root growth which enhances the N availability to plant and eventually increases its concentration in plants. The interaction between F and P was significant at both the levels of sodicity.

Table 12: Nitrogen concentration (%) in barley grain as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						**ESP 27.1**					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	1.63	1.34	2.53	2.67	1.79	0	1.36	1.46	1.73	1.69	1.56
12.5	1.06	2.45	0.93	2.74	1.80	12.5	2.10	1.24	2.83	1.35	1.88
25	2.44	1.13	1.94	2.24	1.94	25	1.47	1.49	3.16	1.59	1.93
50	1.53	2.44	2.85	1.34	2.04	50	3.10	1.84	3.60	3.53	3.02
Mean	1.67	1.84	2.06	2.25		Mean	2.01	1.51	2.83	2.04	
LSD ($p \le 0.05$)						LSD ($p \le 0.05$)					
P = 0.09; F = 0.09; P X F = 0.18						P = 0.11; F = 0.11; P X F = 0.22					

Table 13: Nitrogen concentration (%) in barley straw as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						**ESP 27.1**					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	0.82	1.40	1.43	1.56	1.30	0	1.49	1.24	0.90	1.23	1.21
12.5	1.50	1.87	1.38	1.71	1.62	12.5	1.23	1.00	1.15	1.84	1.31
25	1.68	1.79	1.84	1.72	1.76	25	1.61	1.56	1.09	1.16	1.36
50	1.93	1.99	2.03	1.94	1.98	50	1.52	1.38	1.39	1.42	1.43
Mean	1.48	1.76	1.67	1.73		**Mean**	1.46	1.30	1.13	1.41	
LSD ($p \le 0.05$)						LSD ($p \le 0.05$)					
P = 0.08; F = 0.08; P X F = 0.15						P = 0.06; F = 0.06; P X F = 0.11					

Sodium

Sodium concentration in both the grain and straw increased with increase in applied F and decreased with increased levels of P in the soil at both sodicity levels but at ESP 27.1 it decreased with increasing levels of F (Tables 14 and 15). The results are in agreement with the findings of Hansen *et al.* (1958) [56] and Singh *et al.* (1979b) [26] who reported that increase in sodium content in the plants with increasing fluoride levels in the soil which may be attributed to the dominance of highly soluble NaF in soil solution with increasing levels of fluoride in the soil. Hussain *et al.* (2016) [43] evinced that the variation in Na concentration in plants in response to P addition under saline conditions could be linked to its accompanying cation (NH_4^+). The increased concentration of Na and reduced concentration of K and Ca at high soil sodicity may be due to the relatively high availability of Na and low availability of K and Ca to the plants grown in soil with high sodicity (Prasad *et al*., 2010) [57]. The interaction of F and P was significant in grain but non-significant in straw at both the levels of sodicity which may be due to the dilution effect in straw.

Table 14: Effect of application of phosphorus and fluoride on sodium concentration (%) in barley grain in relation to sodicity

ESP 6.2						**ESP 27.1**					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	0.024	0.024	0.025	0.025	0.025	0	0.109	0.111	0.122	0.112	0.114
12.5	0.024	0.024	0.025	0.025	0.024	12.5	0.101	0.101	0.099	0.104	0.102
25	0.023	0.023	0.023	0.024	0.023	25	0.092	0.089	0.086	0.097	0.091
50	0.022	0.022	0.021	0.022	0.022	50	0.069	0.069	0.068	0.071	0.069
Mean	0.023	0.023	0.024	0.024		Mean	0.093	0.093	0.094	0.096	
LSD ($p \le 0.05$)						LSD ($p \le 0.05$)					
P = 0.001; F = 0.001; P X F = 0.002						P = 0.003; F = 0.003; P X F = NS					

Table 15: Effect of application of phosphorus and fluoride of sodium concentration (%) in barley straw in relation to sodicity

ESP 6.2						**ESP 27.1**					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	0.198	0.212	0.248	0.302	0.240	0	1.166	1.180	1.215	1.251	1.203
12.5	0.190	0.208	0.239	0.254	0.223	12.5	1.162	1.195	1.153	1.168	1.170
25	0.151	0.183	0.198	0.229	0.191	25	1.063	1.085	1.076	1.124	1.087
50	0.127	0.151	0.183	0.191	0.163	50	0.993	1.025	1.121	1.044	1.046
Mean	0.167	0.189	0.217	0.244		Mean	1.096	1.121	1.142	1.147	
LSD ($p \le 0.05$)						LSD ($p \le 0.05$)					
P = 0.007; F = 0.007; P X F = NS						P = 2.1; F = 2.1; P X F = NS					

Potassium

Potassium concentration in both the grain and straw decreased with increasing levels of applied F and increased with increased levels of P in the soil (Tables 16 and 17). Moreover, K concentration decreased at higher ESP which may be attributed to the immobilization of added F by the formation of relatively insoluble intermediate compounds of Ca and Mg resulting in higher solubility of Na which in turn might have an effect on potassium content (Singh *et al*. 1979b; Bhardwaj, 2006) [26, 28]. The interaction between F and P was non-significant in grain and straw at both ESP levels except at 6.2 in case of straw. Abid *et al*. (2002) [55] evinced that under saline-sodic soil conditions the uptake of Na^+ was higher which concomitantly might have reduced the uptake of potassium in wheat straw.

Table 16: Potassium concentration (%) in barley grain as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg-1)	F added (mg kg-1)					P added (mg kg-1)	F added (mg kg-1)				
	0	40	80	160	Mean		0	40	80	160	Mean
0	0.353	0.346	0.344	0.343	0.347	0	0.342	0.342	0.339	0.336	0.340
12.5	0.357	0.349	0.346	0.344	0.349	12.5	0.344	0.344	0.342	0.338	0.342
25	0.360	0.351	0.349	0.347	0.352	25	0.349	0.346	0.349	0.341	0.346
50	0.361	0.353	0.351	0.350	0.354	50	0.354	0.351	0.348	0.345	0.350
Mean	0.358	0.350	0.348	0.346		Mean	0.347	0.346	0.345	0.340	
LSD (p ≤ 0.05)						LSD (p ≤ 0.05)					
P = 0.007; F = 0.007; P X F = NS						P = 0.008; F = 0.008; P X F = NS					

Table 17: Potassium concentration (%) in barley straw as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg-1)	F added (mg kg-1)					P added (mg kg-1)	F added (mg kg-1)				
	0	40	80	160	Mean		0	40	80	160	Mean
0	1.32	1.29	1.25	1.24	1.28	0	1.21	1.19	1.17	1.14	1.18
12.5	1.34	1.30	1.29	1.28	1.30	12.5	1.24	1.22	1.19	1.18	1.21
25	1.38	1.34	1.32	1.29	1.33	25	1.29	1.26	1.22	1.19	1.24
50	1.47	1.46	1.44	1.39	1.44	50	1.34	1.32	1.31	1.29	1.32
Mean	1.38	1.35	1.33	1.30		Mean	1.27	1.25	1.22	1.20	
LSD (p ≤ 0.05)						LSD (p ≤ 0.05)					
P = 0.03; F = 0.03; P X F = 0.07						P = 0.05; F = 0.05; P X F = NS					

Calcium

Calcium concentration in both the grain and straw decreased significantly with increasing levels of applied F and increased with applied P in the soil. However, it decreased with ESP levels with respect to both F and P levels (Tables 18 and 19). The decrease in calcium content of both the grain and straw may be ascribed to the possible precipitation of calcium as CaF_2 which is likely to be formed immediately after the application of fluoride in the soil. Bhardwaj, (2006) [28] also reported similar results in screen house experiment on wheat but Singh *et al*. (1979b) [26] reported that P application increased Ca concentration with increasing levels of sodicity. The interaction was significant for grain and straw at both the levels of sodicity although statistically non-significant at ESP 27.1 for grain.

Table 18: Calcium concentration (%) in barley grain as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg-1)	F added (mg kg-1)					P added (mg kg-1)	F added (mg kg-1)				
	0	40	80	160	Mean		0	40	80	160	Mean
0	0.26	0.25	0.17	0.16	0.21	0	0.21	0.18	0.17	0.15	0.18
12.5	0.27	0.21	0.19	0.19	0.21	12.5	0.23	0.19	0.18	0.16	0.19
25	0.28	0.23	0.22	0.21	0.23	25	0.23	0.21	0.19	0.18	0.20
50	0.34	0.31	0.29	0.28	0.31	50	0.26	0.23	0.21	0.19	0.22
Mean	0.29	0.25	0.22	0.21		Mean	0.23	0.20	0.19	0.17	
LSD (p ≤ 0.05)						LSD (p ≤ 0.05)					
P = 0.01; F = 0.01; P X F = 0.03						P = 0.02; F = 0.02; P X F = 0.04					

Table 19: Calcium concentration (%) in barley straw as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg-1)	F added (mg kg-1)					P added (mg kg-1)	F added (mg kg-1)				
	0	40	80	160	Mean		0	40	80	160	Mean
0	0.41	0.36	0.34	0.35	0.37	0	0.36	0.35	0.34	0.31	0.34
12.5	0.45	0.42	0.41	0.38	0.42	12.5	0.39	0.37	0.34	0.32	0.35
25	0.49	0.47	0.43	0.41	0.45	25	0.40	0.37	0.36	0.39	0.38
50	0.46	0.48	0.44	0.43	0.45	50	0.44	0.41	0.39	0.31	0.39
Mean	0.45	0.43	0.41	0.39		Mean	0.40	0.38	0.36	0.33	
LSD (p ≤ 0.05)						LSD (p ≤ 0.05)					
P = 0.012; F = 0.012; P X F = 0.024						P = 0.016; F = 0.016; P X F = NS					

Micronutrients (Zn, Cu, Mn and Fe)

The concentration of micronutrients in both the grain and straw decreased with increasing levels of F and P in the soil at both levels of sodicity (Tables 20-27). The decrease in zinc concentration may be due to an increase in pH as a result of increasing F levels in the soil. The addition of F in the soil has been reported to increase the hydroxyl (OH^-) concentration. Thus there may be precipitation of micronutrients into insoluble forms which might have resulted in reduced availability of micronutrients to plants. This reduced availability due to interference of applied phosphorus is very common in soils. The decrease in copper content in barley grain and straw may be due to its possible precipitation into unavailable forms in the soil. The results were in agreement with the findings of Singh *et al*. (1979b) [26]. Elrashidi *et al*. (1998) [27] also opined that P additions decreased micronutrient uptake by plants grown on the alkaline soil. Swarup (1985) [58] also reported that higher ESP decreased concentration of Fe, Mn, Zn and Cu in rice.

Table 20: Effect of application of phosphorus and fluoride of zinc concentration (mg kg^{-1}) in barley grain in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	21.56	20.74	20.50	19.27	20.52	0	22.29	21.67	20.57	19.32	20.96
12.5	19.02	17.80	19.56	20.38	19.19	12.5	20.65	19.75	18.72	20.22	19.83
25	18.99	19.33	18.69	16.71	18.43	25	20.06	19.50	19.65	19.12	19.58
50	19.20	19.03	16.14	17.64	18.00	50	19.79	18.59	17.00	16.51	17.97
Mean	19.69	19.22	18.72	18.50		Mean	20.70	19.88	18.99	18.79	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.41; F = 0.41; P X F = 0.83						P = 0.63; F = 0.63; P X F = NS					

Table 21: Effect of application of phosphorus and fluoride on zinc concentration (mg kg^{-1}) in barley straw in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	15.77	14.36	12.74	13.54	14.10	0	12.95	12.02	10.56	9.93	11.37
12.5	12.37	12.43	12.08	11.30	12.05	12.5	13.10	11.88	9.77	9.95	11.18
25	11.14	11.35	11.51	10.93	11.23	25	11.89	9.72	11.00	10.94	10.88
50	10.94	11.01	10.86	10.99	10.95	50	11.13	9.88	11.22	9.46	10.42
Mean	9.58	9.08	8.83	8.77		Mean	12.27	10.87	10.64	10.07	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.56; F = 0.56; P X F = 1.12						P = 0.59; F = 0.59; P X F = 1.17					

Table 22: Copper concentration (mg kg^{-1}) in barley grain as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	12.24	11.94	11.74	11.16	11.77	0	2.68	2.37	2.11	2.07	2.31
12.5	11.26	11.03	10.77	10.43	10.87	12.5	2.46	2.19	2.43	1.97	2.26
25	9.87	9.77	9.45	9.05	9.53	25	2.24	2.32	2.01	2.05	2.16
50	8.85	8.51	7.72	7.05	8.03	50	2.16	1.92	1.99	2.11	2.05
Mean	10.56	10.31	9.92	9.42		Mean	2.38	2.20	2.14	2.05	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.60; F = 0.60; P X F = NS						P = 0.10; F = 0.10; P X F = 0.20					

Table 23: Copper concentration (mg kg^{-1}) in barley straw as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	1.19	1.17	1.08	1.12	1.14	0	1.33	1.14	0.96	0.94	1.09
12.5	1.22	0.94	1.24	0.98	1.10	12.5	0.99	0.91	0.96	0.93	0.95
25	1.08	1.31	0.74	0.93	1.02	25	0.95	0.91	0.99	0.74	0.90
50	1.11	0.86	1.15	0.76	0.97	50	0.98	1.12	0.74	0.63	0.87
Mean	1.15	1.07	1.05	0.95		Mean	1.07	1.02	0.91	0.81	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.08; F = 0.08; P X F = 0.15						P = 0.07; F = 0.07; P X F = 0.13					

Table 24: Manganese concentration (mg kg^{-1}) in barley grain as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	**F added (mg kg^{-1})**					**P added (mg kg^{-1})**	**F added (mg kg^{-1})**				
	0	**40**	**80**	**160**	**Mean**		**0**	**40**	**80**	**160**	**Mean**
0	10.51	10.77	10.64	9.70	10.40	0	10.29	10.60	9.89	9.68	10.12
12.5	10.02	8.91	9.33	9.65	9.48	12.5	10.53	10.29	9.03	9.18	9.76
25	8.82	8.86	7.61	7.88	8.29	25	8.65	8.12	8.61	7.56	8.23
50	8.98	7.76	7.72	7.86	8.08	50	9.15	6.78	7.54	6.22	7.42
Mean	9.58	9.08	8.83	8.77		Mean	9.66	8.95	8.77	8.16	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.45; F = 0.45; P X F = 0.90						P = 0.48; F = 0.48; P X F = 0.97					

Table 25: Manganese concentration (mg kg^{-1}) in barley straw as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	F added (mg kg^{-1}) 0	40	80	160	Mean	P added (mg kg^{-1})	F added (mg kg^{-1}) 0	40	80	160	Mean
0	19.95	20.21	19.34	20.03	19.88	0	20.82	19.31	18.28	19.00	19.35
12.5	17.67	19.31	18.45	15.49	17.73	12.5	19.92	18.78	18.58	17.33	18.65
25	17.86	17.12	18.44	16.17	17.40	25	15.81	14.80	14.86	12.82	14.57
50	17.22	15.50	14.90	16.89	16.13	50	15.17	13.71	13.59	12.78	13.82
Mean	18.17	18.04	17.78	17.14		Mean	17.93	16.65	16.33	15.48	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 0.36; F = 0.36; P X F = 0.73						P = 0.49; F = 0.49; P X F = 0.98					

Table 26: Iron concentration (mg kg^{-1}) in barley grain as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	F added (mg kg^{-1}) 0	40	80	160	Mean	P added (mg kg^{-1})	F added (mg kg^{-1}) 0	40	80	160	Mean
0	33.95	33.48	33.72	32.02	33.30	0	34.66	33.13	33.32	32.69	33.45
12.5	31.35	30.62	28.94	29.36	30.07	12.5	31.86	30.63	28.77	29.14	30.10
25	30.24	29.13	28.41	27.25	28.76	25	30.44	29.45	28.17	27.42	28.87
50	27.87	27.56	27.77	26.03	27.31	50	29.25	28.07	27.10	26.52	27.74
Mean	30.85	30.20	29.71	28.67		Mean	31.55	30.32	29.34	28.94	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 1.04; F = 1.04; P X F = NS						P = 1.27; F = 1.27; P X F = NS					

Table 27: Iron concentration (mg kg^{-1}) in barley straw as affected by application of phosphorus and fluoride in relation to sodicity

ESP 6.2						ESP 27.1					
P added (mg kg^{-1})	F added (mg kg^{-1}) 0	40	80	160	Mean	P added (mg kg^{-1})	F added (mg kg^{-1}) 0	40	80	160	Mean
0	25.18	23.92	24.08	22.87	24.01	0	27.08	25.75	24.68	23.32	25.21
12.5	21.93	20.62	21.18	19.89	20.91	12.5	24.23	23.08	22.95	20.36	22.65
25	21.14	20.89	18.70	17.98	19.68	25	20.42	20.61	19.81	20.96	20.45
50	20.30	19.04	19.61	18.72	19.42	50	21.02	20.37	20.40	18.66	20.11
Mean	22.14	21.12	20.89	19.87		Mean	23.19	22.45	21.96	20.83	
LSD ($p \leq 0.05$)						LSD ($p \leq 0.05$)					
P = 1.11; F = 1.11; P X F = NS						P = 0.93; F = 0.93; P X F = NS					

Conclusion

Germination percentage, plant height, total chlorophyll content, spike length, number of grains per ear head, grain and straw yield decreased with increasing levels of fluoride at both ESP levels whereas with increasing application of phosphorus these parameters increased at both the levels of sodicity. Fluoride concentration in both the grain and straw increased with increasing levels of F and Pat both levels of sodicity. Phosphorus concentration also increased with increasing levels of P in both grain and straw but it decreased with increasing levels of applied F and ESP. The adverse effect of added F was more marked at higher ESP and the deleterious effect of added fluoride was counteracted to some extent by addition of phosphorus. The counteracting effect of P through immobilization of F is evident by the simultaneous decrease in K, Ca and P content and increase in Na in both the grain and straw with increasing levels of F. The application of F and P resulted in decreased concentration of micronutrients i.e. Zn, Cu, Mn and Fe in both the grain and straw.

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