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ARAŞTIRMA MAKALESİ/**RESEARCH ARTICLE**

EFFECT OF IRRIGATION WATER CONTAINING HIGH FLUORINE ON SOIL AND SOME FIELD CROPS

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ABSTRACT

Water polluted by fluorine (F) may be hazardous to humans, animals, and plants. The purpose of this study was to determine the F content at the source of planned Eskisehir-Kızılcaören Dam and to investigate the effect of F in the irrigation water on soil and some field crops in this project area. The F content of soil ranged from 1.2 to 16.2 mg kg^{-1} while the F content of irrigation water was determined to be between 2.1 and 8.0 mg L^{-1}. Irrigation with high F containing water has been experienced for more than 40 years and the F levels in the leaves of the crops commonly grown in the area, which include oats, winter wheat, potato, alfalfa and chickpea, were found to be less than 0.1 mg kg^{-1}. These results indicate that F concentration of up to 8.0 mg L^{-1} in the irrigation water pose no hazard to soil and crops grown in the area.

Key Words: Irrigation, Water, Pollution, Fluorine, Soil, Crops

YÜKSEK FLOR İÇERİĞİNE SAHİP SULAMA SUYUNUN TOPRAĞA VE BAZI TARLA BİTKİLERİNE ETKİSİ

ÖZ

Flor (F) ile kirlenmiş sular insanlara, hayvanlara ve bitkilere zararlı olabilir. Bu çalışmanın amacı, planlanan Eskişehir-Kızılcaören Sulama Göleti su kaynağ ındaki F düzeyi ile sulama suyundaki F'in toprak ve bazı bitkilere etkisini araştırmaktır. Çalışma yerine ait toprakların F içeriğ i, 1.2-16.2 mg kg^{-1} arasında değ işmektedir. Sulama suyundaki F düzeyi ise 2.1 ile 8.0 mg L^{-1} arasında tespit edilmiştir. Yüksek F içeriğ ine sahip sulama suyu ile 40 yıldan fazla sulama yapılmasına rağ men, bölgede yaygın olarak yetiştirilen kışlık buğ day, yonca, patates, nohut ve yulaf yapraklarında F içeriğ i 0.1 mg kg^{-1}'dan daha düşük düzeyde tespit edilmiştir. Bu sonuçlar, 8.0 mg L^{-1} 'e kadar F içeren sulama suyunun toprağ a ve bölgede yetiştirilen tarla bitkilerine zararlı bir etkisinin olmadığ ını göstermektedir.

Anahtar Kelimeler : Sulama, Su, Kirlilik, Flor, Toprak, Bitkiler

1. INTRODUCTION

Sustainability of irrigated agriculture requires consideration of the quantity and quality of the irrigation water. Irrigation water quality can be affected either by human activities like irrigation, industrial and municipal activities, or by natural processes. This paper deals with fluorine (F) pollution caused by natural processes in the water withdrawn from the planned Kızılcaören Dam. The aim is to investigate the effect of F in irrigation water on the F content of soil and field crops in the Eskisehir Province of Turkey.

F pollution in irrigation water is not a frequently experienced case, however if so, it may be hazardous to human and animal health, and plants. Nevertheless, water resources containing high F in the some regions in Turkey, e.g. Doğ ubeyazıt and Isparta Regions, Güllü Village in Uşak and Kızılcaören Village in Eskişehir have been referred in literature (Oruç, 1988a).

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A dam is planned by the General Directorate of Rural Affairs of Turkish Republic in order to irrigate the fields of Kızılcaoren Village in Eskisehir Province. Meanwhile, F concentration in the irrigation water was determined to vary between 3 and 6 mg L^{-1} (DSİ, 1995; KH, 1996). This level was higher than allowable F level for irrigation water (Uslu and Türkman, 1987; UNU, 2003). Before constructing the dam serving for irrigation purposes, it must be checked whether F in irrigation water has any hazardous effect on soil and crops grown in the area or not. For this purpose, a preliminary study was carried out in the region and the F content in water was measured as 2.9 mg L^{-1} in January 2000. Additionally, the farmers have been using the water of Pınarbaşı Creek, which is the main water resource of the dam, for a long time. There have been no specific scientific data indicating the effect of F in the water on soil and crops in this region. Therefore, the local authorities and the decision-makers hesitated to construct an irrigation dam due to high F content in the water.

Aksit et al. (1980) carried out a study in Kızılcaören as some health problems such as fluorisis in the village has been faced. According to their findings, the F content in three fountains ranged from 3.8 to 4.9 mg L^{-1}. They also determined that excess F in drinking water affected the teeth of all children who have grown in the village. The tooth problems included mottling, staining, decaying or pitting of enamel, depending of the degree of fluorisis. In addition, 45 % of 166 adults in the village had suffered from skeleton fluorides. In order to overcome the problem, the inhabitants started to use another spring, which does not contain F for drinking purposes. Kırıkoğ lu (1988) referred to high F level in drinking water of Kızılcaören Village due to fluorspar (CaF_2) deposits in the catchment area. Oruç (1998b) measured 7 mg L^{-1} F in the former drinking water of the Kızılcaören Village.

Common mineral forms of F are fluorspar (CaF_2), fluoroapatite [$Ca_5(PO_4)_3F$], cryolite (Na_3AlF_6). The F level in soil water commonly range from 10 to 20 mg kg^{-1}, whereas it ranges from 0.2 to 20 mg kg-1 in plants, except for tea and some pasture plants. Plant uptake of F from the soil is passive, but it is normally phytotoxic (Pais and Jones, 1997). Additionally, F is not an essential plant nutrient. Its importance stems only from the damage it causes in plants near or fairly near to industries emitting fluorine; hydrogen fluorosilicates. F compounds do not disperse so rapidly in the atmosphere as other gases. The main sources of F and F-containing emissions include aluminum smelters, factories producing hydrogen fluoride, plants processing crude phosphate, cement works, glassworks and potteries (Bergmann, 1992).

Campen (1991) stated that water is another important source of F. Uncontaminated surface water generally contains less F than water derived from spring or wells. In endemic fluorisis areas, deep water may percolate through fluorapatite and, if so, the F content can range from 3 to 40 mg kg^{-1}. Oruç (1983) analyzed F in 23 water samples in Dogubeyazit Region of Turkey which had been used for drinking and irrigation purposes. The F content in these water samples ranged from 0.06 to 13.8 mg L^{-1}. In 17 of the samples, the F content was greater than 1 mg L^{-1} stated for drinking water by World Health Organization (WHO). Fluorisis was detected in teeth and skeletons of humans and animals that lived in the region.

This study aims to examine F content of water resource of the Kızılcaören Irrigation Dam Project in Eskişehir Province of Turkey and to investigate the effect of fluorine in irrigation water on soil and some field crops.

2. MATERIAL and METHODS

2.1 Study Area

The study area is near the Kızılcaören Village in Eskişehir, and is 72 km away from the Eskişehir Province. It is situated at latitude 39° 41' N and longitude 31° 12' E. The altitude is 755 m. The total agricultural area of the village is approximately 3000 ha, and the soil which has curly and inclined topography in the region is Brown-Forest Soils formed at hills and slope of hills, and collivial formed at the bottom of the hills (KH, 1996). Soil map of the area is shown in Figure 1.

The region has typical terrestrial climatological properties. According to the long-term data, the annual average temperature, precipitation, relative humidity and wind speed are 11.2 °C, 313 mm, 58 %, and 2.0 m $sec.^{-1}$, respectively (DMİ, 1997).

The main water resource in the catchment area is Pınarbaşı Creek and its discharge ranges between 10 and 20 L sec^{-1}, its flow in the summer is as low as 10 L $sec.^{-1}$. Water amount of 631 000 m^3 can be collected and stored in the reservoir that is planned to be constructed. An irrigation concrete dike and small channels have already been built in 1962. The area of 20 ha has been irrigated by means of these channels. The channels are nowadays worn out and no longer capable of delivering sufficient water to irrigate 20 ha. Thus, there exists a necessity to increase the irrigated area near Kızılcaören through , constructing new channels and an irrigation dam on the Pınarbaşı Creek. Thus, total irrigated area will then increase to 191 ha. Presently, the basin and furrow methods have been used for irrigation, and after construction of the reservoir, the sprinkler irri-

Table 1. Analysis Results of Pınarbaşı Creek Water

Water sample no	pH	EC ($dS\ m^{-1}$)	Cations ($meq\ L^{-1}$)				Anions ($meq\ L^{-1}$)				SAR
			Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	
1	8.0	0.54	0.89	0.09	2.35	2.45	1.40	3.80	0.50	0.08	0.57
2	7.9	0.66	0.96	0.03	3.15	2.60	0.60	5.20	0.90	0.04	0.57
3	8.1	0.55	0.89	0.09	2.60	2.85	1.40	4.00	0.95	0.08	0.54

SAR: Sodium absorption ratio, EC: Electrical conductivity

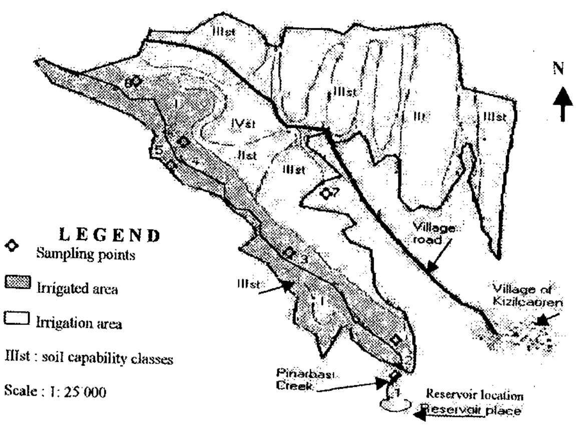

Figure 1. Soil Map of the Study Area and the Sampling Points.

gation method will be used.

2.2. Sampling of Soil, Water, Plants and Analysis Methods

Water samples were taken from different points along the creek and analyzed by ion selective electrode for F. Soil samples were taken from six points along the profile to represent the area irrigated by the creek water, and one point from non-irrigated area for control. F in soil was determined by the method of ion selective fluoride electrode described by Pluger and Friedrich (1972). Hence, F contents in the soil were measured by means of the electrode immersed into a soil paste.

Leaves of the plants were collected at the flowering stage from oats, winter wheat, barley, chickpea, alfalfa and potato grown in the same fields from which the soil samples were taken. The plant samples were prepared for analysis after being dried in an oven at 65 °C and were grinded. The F content of the plants was determined with the method of ion selective fluoride electrode described by Jacobson and Heller (1972).

3. RESULTS and DISCUSSION

3.1 The Analysis Results of the Water Samples

The results of the Pınarbaşı Creek water and drinking water of the village, and F content in these water samples are given in Table 1 and 2, respectively. Considering the results, there appears no significant problem in the water, except the F content. Examined F concentration in irrigation water varied from 2.1 to 8.0 mg L^{-1} (Table 2). Oruç (1998b) determined 7 mg L^{-1} F in the previous drinking water, which is in the same watershed. The results showed an increase in F level in water from spring to summer. Taking into account of the results, the level of F content in both the previous drinking water and irrigation water are higher than the WHO guidelines and irrigation water quality criteria, e.g 1.0 mg L^{-1} (UNU, 2003). The reason of the high F level may be attributed to hydrogeological structures of the study area. Similarly, Kırıkoğ lu (1988) stated that high F level in former drinking water of Kızılcaören resulted from fluorspar (CaF_2) deposits in the same catchment area.

3.2. F Level and Various Chemical and Physical

Table 2. Fluorine Levels In The Water Resources of Study Area Examined at Different Dates.

Sampling place and no	Sampling Dates		
	03.01.2001	01.05.2001	9.10.2001
		Fluorine level (mg L^{-1})	
Planned reservoir location (Pınarbaşı Creek) (1)	2.9	5.5	8.0
Spring water near the Pınarbaşı (2)	2.1	3.8	5.0
Water inlet to fields (Pınarbaşı Creek water) (3)	2.9	5.5	8.0
Present drinking water for village (Güllük spring) (4)	0.0	no data-	< 0.1
Former drinking water for village (Cingir spring) (5)	no data	no data	5.5

Table 3. Various Physical and Chemical Analysis Results of in The Study Area

Soil samples no	Soil depth. (cm)	pH	EC (ds m^{-1})	Sat. (%)	Org. matter (%)	Lime (%)	Particle distrubution (%) sand	silt	clay	Texture class
1	0-30	8.0	0.64	55	0.01	1.80	73	16	11	SL
	30-60	7.8	0.66	45	1.36	1.75	81	12	7	LS
2	0-30	7.8	0.83	61	4.03	4.67	62	16	22	SCL
	30-60	7.7	0.74	62	2.51	4.38	57	16	27	SCL
	60-90	7.8	0.63	59	0.62	3.79	58	14	28	SCL
3	0-30	7.9	0.96	63	1.86	9.63	55	16	29	SCL
	30-60	7.8	0.68	61	0.71	9.34	53	14	33	SCL
	60-90	7.8	0.62	61	0.44	9.92	55	14	31	SCL
4	0-30	7.8	0.79	66	2.95	3.21	50	19	31	SCL
	30-60	7.6	0.66	66	0.60	3.21	48	25	27	SCL
	60-90	7.7	0.58	66	0.95	2.62	48	27	25	SCL
5	0-30	7.9	0.63	62	2.59	8.03	49	23	28	SCL
	30-60	7.8	0.61	69	2.81	7.88	47	22	31	SCL
	60-90	7.8	0.68	69	1.46	7.15	51	18	31	SCL
6	0-30	8.0	0.63	57	1.73	6.57	62	16	22	SCL
	30-60	7.9	0.48	55	1.46	7.15	60	14	26	SCL
	60-90	8.0	044	55	0.23	6.86	64	16	20	SCL
7	0-30	7.7	0.34	61	0.85	1.46	61	12	27	SCL
	30-60	7.8	0.45	66	0.31	3.36	57	14	29	SCL
	60-90	7.8	0.35	64	0.11	3.21	52	16	32	SCL

EC: Electrical conductivity, Sat.: Saturation, SL : Sandy-Loam, LS: Loamy-sand, SCL : Sandy-Clay-Loamy

Properties of Soil

Various chemical and physical analysis results of soil in the study area are presented in Table 3. Soils that lie along the right and the left banks of the Pınarbaşı Creek (Figure 1) were predominately sandy clay loams (Table 3).

F content in the soil was determined to be between 1.2 and 16.2 mg kg^{-1} (Table 4). Whereas, F content was found to vary in a range varying from 10 to 7000 mg kg^{-1}, by Bergmann (1992), and Pais and Jones (1997). The average value of F concentration in soil was calculated to be 280 mg kg^{-1} and soluble portion of F in normal soil was found to be 10-20 mg kg^{-1}. Taking into account these data of F in the soil, it can be stated that there is no excess F in the soil of the study area. Furthermore, there was no significant difference in terms of F content between the soils treated by the irrigation water, which contains high level of F, nonirrigated soils with F content of 8.4-11.5 mg kg^{-1}, and the other soils irrigated by the creek water for a long period of time (more than 40 years) has an F content of 1.2-16.2 mg kg^{-1}.

It is shown that there is no pollution or accumulation of F in the soil due to excess F in the irrigation water. Although it has been irrigated with water con-

Table 4. F content of Soil İrrigated By Pınarbaşı Creek Water (mg kg^{-1})

Soil depth (cm)	Soil samples places and numbers						
	1	2	3	4	5	6	7
0-30	7.0	8.4	7.9	13.5	10.5	8.0	11.5
30-60	9.5	8.0	2.5	8.0	13.0	8.3	11.5
60-90	--	14.2	1.2	9.5	16.2	7.4	8.4

1: Reservoir place (creek bed); 2,3,4,6: Irrigating fields (Right Bank), 5: irrigating field (left bank), 7: Nonirrigating field (Right Bank) taining high F concentration for many years, no accumulation of F in the soils has been detected which may be due to the curly and inclined topography and to generally sand-clay-loam texture of the soils.

Additionally, F concentration in soil is inherited from parent material, whereas its distribution in soil profile is a function of soil-forming process, of which the degree of weathering and texture are the most pronounced. On the other hand, according to the researches carried out between years 1954 - 1984 in the same catchment area (MTA, 2001), mineral composition of the area was 37.5 % fluorspar (CaF_2), 31.0 % barite ($BaSO_4$), 9.4 % calcite ($CaCO_3$), 3.4 % ferrous minerals, 3.1 % quarts (SiO_2) and the others. Consequently, either high F level in the water or existing F in the soil may be attributed to dominating fluorspar in the catchment area.

Moreover, Ca is well known mineral to reduce F deposition. The solubility of CaF_2 (Ksp= 4.0 x 10^{-11}) is about 100 times lower than that of calcite (Ksp= 4.8x10^{-9}) (Ünal, 1979). All pH values in Table 3 are greater than 7.6 and the samples contain calcite. F concentrations in the soil solution are being controlled and constrained by Ca activity, which in turn is controlled to a large extent by calcite equilibria. In other words, the dissolution of calcite maintains the Ca concentration at levels that will constrain the F concentrations. It also explains why soil that has been irrigated for more than 40 years have similar F content as those that have not been irrigated. In addition, the negative impact of F can be eliminated by liming the substrate to raise the pH value to above 6.5 (Bergmann, 1992) This verifies the properties of the regional soil (Table 3).

3.3 F Content of the Crops

Plant samples were taken from the same fields where the soil samples were collected. For that reason, the same sampling numbers for the soils and the crops were used (Table 4 and 5). The F contents determined in the leaves of the crops (oats, wheat, potato, alfalfa and chickpea) are given in Table 5. F levels for all the crops were smaller than 0.1 mg kg-1. Furthermore, Ayyıldız (1983) stated that F in water does not have hazardous effects on soil and plants. There was no evidence that F is essential for plant growth (Fleischer, 1974; Bergmann, 1992). Moreover, Pais and Jones (1997) stated that F content in plants ranged from 0.2 to 20 mg kg^{-1} except in tea and some pasture plants. Additionally, plant uptake from the soil was passive, and uptake was not normally phytotoxic, and normal F background level in plant leaves was generally less than 30 mg kg^{-1} . In addition to this, Singh et al. (1995) determined that F content up to 60 mg L^{-1} in the irrigation water did not affect plant.

Considering the previous studies, F content in the leaves of the crops have been found to be very low

Table 5. The F content in The of Leaves of The Crops Grown and İrrigated by Pınarbaşı Creek Water

Sample No	Crops		F contents (mg kg^{-1})
2	Oats	(irrigated)	< 0.1
3	Potato	(irrigated)	< 0.1
4	Wheat	(irrigated)	< 0.1
5	Wheat	(irrigated)	< 0.1
5a	Alfalfa	(irrigated)	< 0.1
6	Wheat	(irrigated)	< 0.1
6a	Alfalfa	(irrigated)	< 0.1
6b	Potato	(irrigated)	< 0.1
7	Chickpea	(non-irrigated)	< 0.1

although they have been irrigated by water naturally polluted by F for a long time. These results verified that there were no hazardous effects of F up to 8.0 mg L^{-1}, which is the maximum level of F in the irrigation water on the crops grown in the same area as referred of different researchers. Moreover, content of F in the leaves of the crops was also under the normal values of F, 0.2-20 mg kg^{-1} (Pais and Jones, 1997), in plants. Also, there were no complaints about the well being of the crops by the farmers as related to high level of F in water. Additionally, it has been found that there were no symptoms resulting from fluorisis.

4. CONCLUSIONS

This study was aimed to investigate the effect of fluorine in irrigation water on soil and some field crops in Kızılcaören irrigation area. Fluorine content in the water of Pınarbaşı Creek, which is the main water resource for the planned irrigation dam, was determined between 2.1 and 8.0 mg L^{-1}. The farmers have been irrigating the arable land by Pınarbaşı Creek water for more than 40 years. Besides, F levels in the soil were found to range from 1.2 to 16.2 mg kg^{-1}. F concentration in the soils may be attributed to parent material as fluorspar (CaF_2) which has the highest ratio in terms of mineral composition of the catchment area and high level of F in water probably due to fluorspar. Still, F level in the soils was not in excess. It may be stated that there was no hazardous accumulation of F in the soils since the normal content of F in soils was around 10-20 mg kg^{-1}.

F content in the leaves of the crops grown in the area and irrigated by the water of Pınarbaşı Creek were less than 0.1 mg kg^{-1}. Considering that the content of F in the plants ranged from 0.2 to 20 mg kg^{-1}, (except in tea and some pasture plants), it may be stated there were no negative impact of the existing F level on the crops grown and irrigated by the Pınarbaşı Creek water in the study area. Besides a high level of F in soil is not in itself harmful to plants. Moreover, F-polluted soils should be ameliorated for a proper growth of vegetation and the application of materials that increase the soil pH and sorption capacity, or fixation ability for F ions.

It may be concluded that, irrigation water containing 2-8 F mg L^{-1} in the Pınarbaşı Creek water will not pose a risk factor for soil and crops grown in the fields of Kızılcaören. However, F level in drinking water is very important. If the amount of F in water is more than 1 mg L^{-1}, it can lead to teeth and skeleton disorders.

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