UNSUSTAINABLE IRRIGATION PRACTICES IN THE BURSA PLAIN, TURKEY

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ABSTRACT

In the Bursa Province, N.W. Turkey, dense urbanisation and subsequent industrialisation has led to large amounts of industrial effluent in local surface waters that are still used by local farmers to irrigate agricultural land. Water from 7 irrigation points was sampled over 4 weeks in the summer of 2001 and analysed for pH, conductivity, and Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn. Adjacent soil samples were also collected, at 0-20 and 20-40 cm depths, from 10 irrigated and 10 non-irrigated arable fields. The water was heavily polluted with heavy metals, and their DTPA-extractable concentrations were significantly higher in the irrigated soils. Even relatively immobile heavy metals such as Pb had accumulated at both sampling depths at high levels. The well-developed cracks in the vertisols of the area facilitate translocation of heavy metals to depth, even those associated with suspended particulates. Irrigation significantly increased the soil organic C and N contents and reduced the pH, CEC and calcium carbonate content. Suspended sediment in irrigation water is also causing systematic changes in soil texture. The current irrigation practices are not sustainable, as the year-upon-year accumulation of heavy metals will eventually cause phytotoxic thresholds to be exceeded, especially once the residual carbonate in the soil has been dissolved and soil pH starts to fall.

Keywords: diffuse pollution; heavy metals; irrigation; vertisol.

INTRODUCTION

The Bursa plain in north-western Turkey has long been used for extensive agricultural production. This is due to its fertile soils with a good water retention capacity and a plentiful supply of clean freshwater from the adjacent mountains for irrigation. However the same water resource, coupled with improved road links, made the area attractive for urban and industrial development. This proceeded at such a pace that legislation to regulate pollution discharge to surface waters of the region has lagged seriously behind the development. This in turn results in a high risk of heavily polluted irrigation water being used for agriculture, with potentially serious health risks.

Noting substantial Cd accumulation in irrigated verstisol soils in the Bursa plain, Aydinalp (1996) analysed irrigation waters in the area. He observed disturbingly high concentrations of a wide range of heavy metals in the Nilufer River and the Ayvali Canal, two water resources used extensively for irrigation, downstream of the industrialised area of the city of Bursa. It was decided to repeat the analysis of the Ayvali Canal water samples, sampling water at more irrigation sites along the stream, and over a longer period in July when it was thought that the pollutant concentrations would be at their highest because of the low flow conditions. Analysing this water is particularly appropriate, because the hot and dry months of June, July and August are when the water is most used for irrigation.

It was further decided to assess the heavy metal, C, N and $CaCO_3$ concentrations, and pH and particle size distribution of irrigated and non-irrigated soils at two sample depths. The objective of using two depths was to gain insight into the extent to which the heavy metals had penetrated down the soil profile.

Heavy metals can occur in several forms in soils: water soluble, exchangeable, bound to the active specific sites of the organic and inorganic soil components, and in the structure of the mineral lattices. Various operationally defined chemical procedures have been proposed for estimating the amounts of heavy metals in the soil available to plants (e.g. Grigg, 1953; Mitchell *et al*., 1957; John, 1972; Symeonides and McRae, 1977; Lindsay and Norvell, 1978). For the present investigation it was decided after careful consideration to measure diethylenetriamine pentaacetic acid (DTPA) extractable concentrations of heavy metals in the soils.

DTPA is widely used as an extractant to indicate the bioavailability of numerous heavy metals in soils. Recently, for example, it has been tested for assessing soil with respect to maize root Cu uptake (Brun *et al*., 2001), uptakes of Cu, Mn, Ni and Pb by tomato and squash (Hanlon *et* al., 1996), and availability of Cu and Zn following compost amendments of soil (Gallardo-Lara *et al*., 1999). A concentration limit of 20 mg kg^{-1} has been advocated for DTPA-extractable Pb in soil to avoid health risk (Wallace and Wallace, 1994). DTPA is also often used for assessing heavy metal contamination in soils in a general sense, without specific reference to plant uptake. It has been used in this way, for example, to assess Cd, Pb and Zn contamination in Polish soils (Chlopecka, 1996), Cd, Cu, Ni and Zn contamination of Norwegian alum shale soils from manures (Arnesen and Singh, 1998), and the effect of acidification of mine tailings on availability of Cd, Cu, Pb and Zn (Shu *et al*., 2001).

DTPA has also been tested for assessing availability of soil Cd to barley (Singh and Myhr, 1998), to sun flower kernals (Li *et al*., 1994) and to potato tubers (McLaughlin *et al*., 1999), but it is not always reported to be a good indicator of bioavailability for Cd. For example, Tsadilas (2000) found that exchangeable Cd was better correlated than DTPA-extractable Cd with tobacco Cd concentration. For Zn, on the other hand, it has been found that DTPA-extractable Zn correlates well with the concentration of Zn that is isotopically exchangeable over 15 days (Sinaj *et al*., 1999). Mellum *et al*. (1998) also found that DTPA was not a good indicator of bioavailability of Cd, Cu, Mn, Ni and Zn. DTPA is frequently used to assess labile element pools in calcareous soils, such as those in the present study (Elkhatib *et al*., 1993; Falatah and Alomran, 1995; Hanlon *et al*., 1996; Gallardo-Lara *et al*., 1999). Although DTPA is not a totally reliable indicator of bioavailabilty for all the elements of interest, it has often been used in pollution assessments for groups of heavy metals, and it was therefore used in the present investigation, which is primarily comparative.

MATERIALS AND METHODS

Ten irrigated and ten non-irrigated soil sites were selected. Irrigated sites were alongside the Ayvali Canal, at regular intervals which covered fully the distribution of irrigation water sampling points. Soil samples were taken at 0-20 cm and 20-40 cm depth, and analysed for their physical and chemical properties. Soil samples were analysed for particle-size distribution by the hydrometer method (Gee and Bauder, 1982), pH at a 1:2 soil:water ratio (McLean, 1982), organic carbon (Nelson and Sommers, 1982), total nitrogen (Bremner and Mulvaney, 1982), calcium carbonate (Nelson, 1982), CEC (Rhoades, 1982), exchangeable cations (Thomas, 1982), and DTPA-extractable Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn (Lindsey and Norvell, 1978).

The Ayvali Canal is the main irrigation water source for soils in the studied area. Seven sampling points were chosen for irrigated soil sites at a spacing of 250-300 m along the stream. The water samples were collected weekly for 4 weeks from 25th June through into July, 2001. The pH, EC, and Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn were determined in the water samples immediately after collection. Because our prime concern was with the total amounts of heavy metals likely to be transferred to the soil via irrigation water, the samples were only filtered, prior to heavy metal analysis, through Whatman No. 42 filters, rather than membrane filters. This appropriately would allow some fine colloidal material to pass through the filter and remain in suspension for subsequent determination.

RESULTS

The results of chemical analyses of the water samples are presented in Figure 1. Water pH varied from 6.50 to 6.70 during four weeks and values decreased slightly downstream from sample 7 to sample 1 (Figure 1a). The stream is seriously polluted with all of the heavy metals tested as can be seen from Figure 1b.

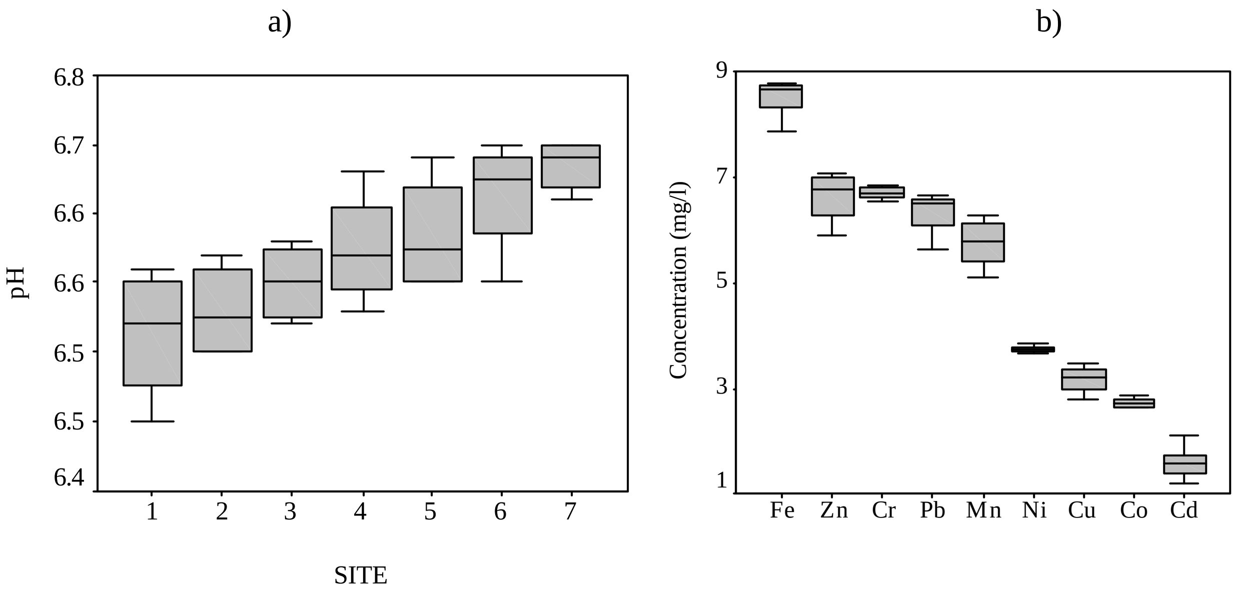

Figure 1. *a) pH levels at sites along the Ayvali canal. b) Heavy metal concentrations in the Ayvali canal water.*

Significance of differences between irrigated and non-irrigated soil data at different depths was tested using independent sample t-tests where data were normally distributed and Mann Whitney U-tests where data were non-normal. All tests were performed at a 0.05 significance level. For irrigated soils, the soil texture is clay throughout all the profiles and clay contents ranged from 45.6% to 59.8%. The CEC values ranged from 39.4 to 52.5 cmol (+) kg^{-1}, and, along with clay content, increased with depth (Figure 2a). Soil pH varied from 7.7 to 8.1 and the values consistently increased with depth (Figure 2b). Exchangeable Ca, Mg and Na values varied from 32.7 to 44.3, 3.5 to 4.7, and 1.7 to 2.4 cmol (+) kg^{-1}, respectively, and increased consistently with depth and hence also with CEC. Exchangeable K varied from 1.6 to 2.4 cmol (+) kg^{-1} and decreased slightly with depth and with increasing clay content. The base saturation was 100% in all the soil profiles due to presence of free $CaCO_3$. The C concentration ranged from 0.8% to 1.9%, and total N from 0.07% to 0.15%, and both decreased consistently with depth as would be expected. The $CaCO_3$ concentrations increased with depth and values ranged from 1.0% to 3.9% (Figure 2b).

For non-irrigated soils, the soil texture was clay in all the soil profiles. Clay contents of the non-irrigated soils were statistically significantly higher than those of the irrigated soils and varied from 55.9% to 67.8%, increasing with depth (Figure 2a). Soil pH varied from 7.9 to 8.3 and increased with depth (Figure 2b). It was significantly higher than pH for the irrigated soils. Soil CEC varied from 49.2 to 58.9 cmol (+) kg^{-1} and values increased with depth. CEC was substantially and significantly higher in the non-irrigated soils (Figure 2a). Exchangeable Ca, Mg and Na values ranged from 43.8 to 53.8, from 3.0 to 3.9 and from 1.1 to 2.0 cmol (+) kg^{-1} respectively, and, like CEC, always increased with depth. Exchangeable K varied from 1.4 to 1.9 cmol (+) kg^{-1}, and slightly decreased with depth however. Base saturation was 100% in all the profiles due to the presence of free $CaCO_3$.

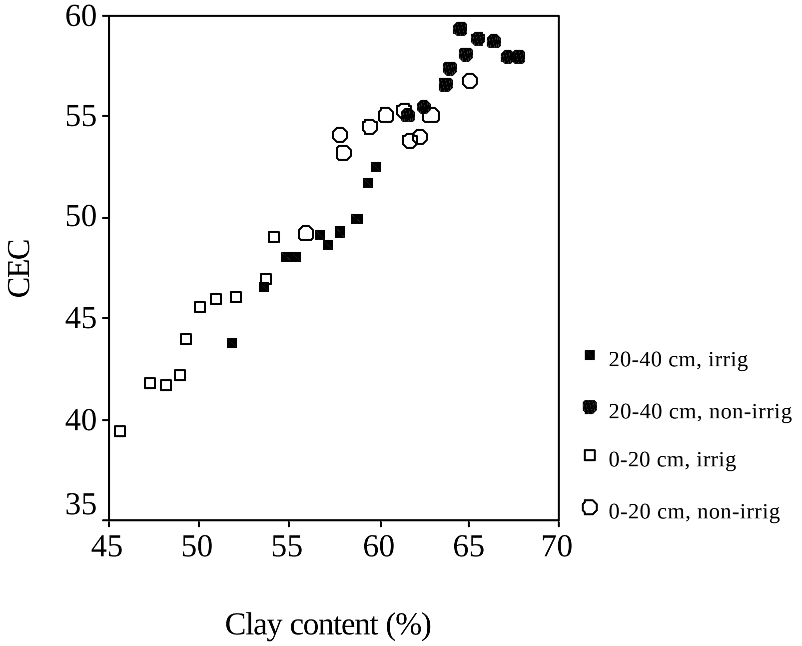

Figure 2(a) *the relationship between CEC and clay content for irrigated and non-irrigated soil samples at two depths.*

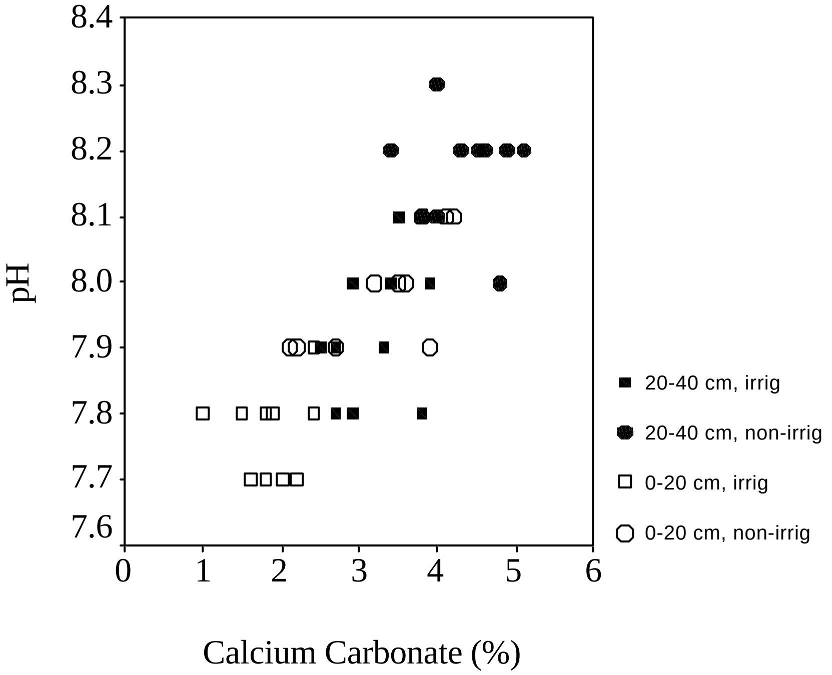

Figure 2(b) *the relationship between pH and percentage calcium carbonate for irrigated and non-irrigated soil samples at two depths.*

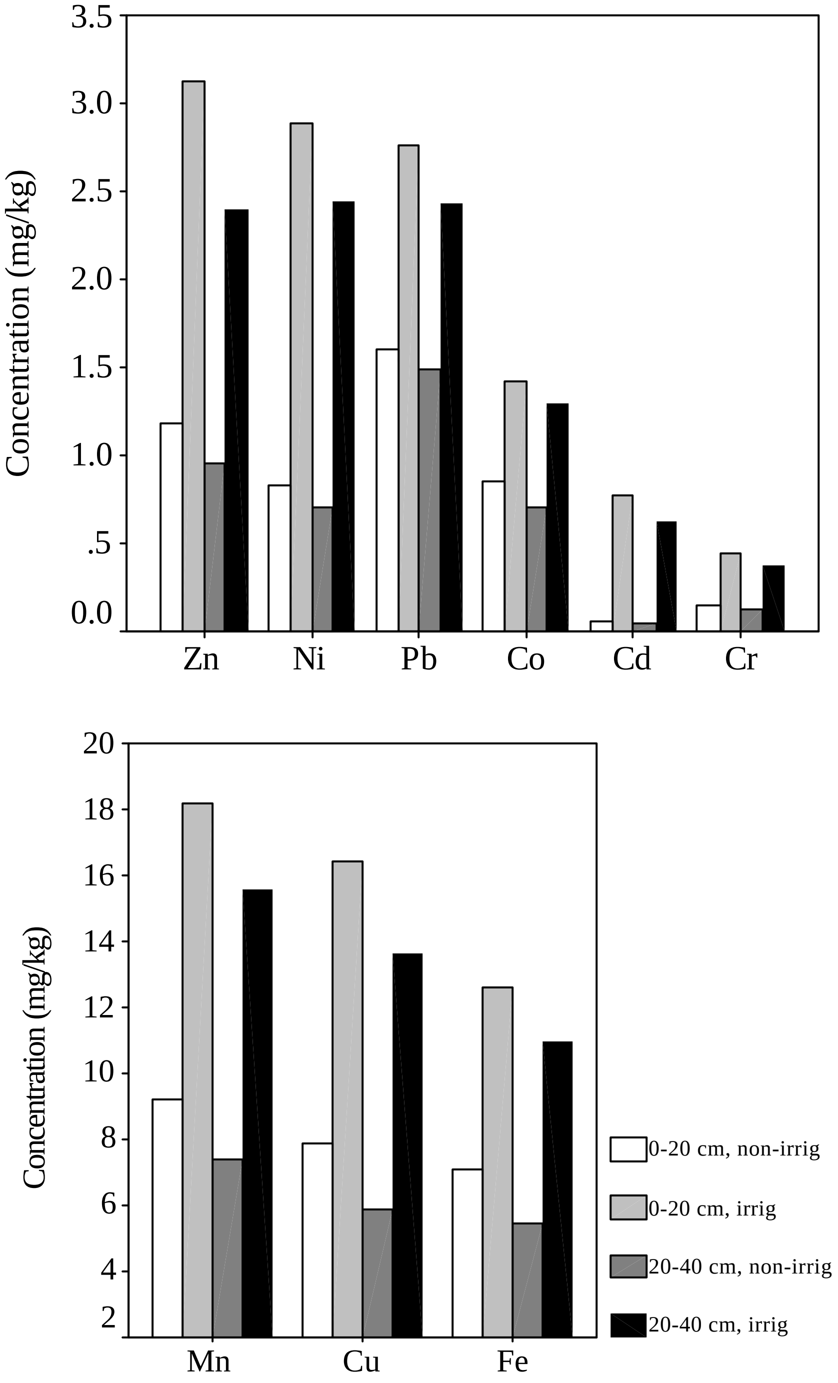

Figure 3. *Mean concentrations of Zn, Ni, Pb, Co, Cd, Cr, Mn, Cu, and Fe from irrigated and non-irrigated soil samples at two depths*

The C and N values ranged from 0.5% to 1.5% and from 0.04% to 0.12% respectively, and decreased with depth. Soil C/N ratios ranged from 10.0 to 14.4. Carbon and N concentrations were significantly higher in the irrigated soils. The $CaCO_3$ concentration varied from 2.1% to 5.1% and increased with depth. It was significantly higher in the non-irrigated soils than in the irrigated soils (Figure 2b).

The DTPA extractable heavy metal concentrations are presented in Figure 3. The extractable concentrations of these elements for irrigated soils were all significantly higher than those for non-irrigated soils. The concentrations of heavy metals found are highest in the topsoil. The values of Fe varied from 9.22 to 14.9 mg kg^{-1}, Mn from 13.2 to 19.1 mg kg^{-1}, Zn from 2.10 to 3.82 mg kg^{-1} and Cu from 10.4 to 19.3 mg kg^{-1}. Cr ranged from 0.31 to 0.50 mg kg^{-1}, Ni from 1.64 to 3.66 mg kg^{-1}, and Co from 1.15 to 1.85 mg kg^{-1}. The values of Pb varied from 2.21 to 2.94 mg kg^{-1} and Cd from 0.37 to 0.95 mg kg^{-1}. In very heavily polluted Polish soils, extractable Cd ranged from 0.41 to 25.5 mg kg^{-1}, Pb from 12.7 to 1730 mg kg^{-1} and Zn from 13.9 to 2800 mg kg^{-1} soil, respectively (Chlopecka, 1996). Compared with these values, the present levels of pollution are still moderate.

DISCUSSION

The water becomes more acid down stream from sampling site 7 to sampling site 1, presumably due to inputs of industrial wastewater. The values of heavy metal concentrations in Fig. 1 are all appreciably higher than those reported in a much more limited previous study, which also involved sampling in June, but only on one occasion and at one location (Aydinalp, 1996). One factor behind the decision to perform the present study was that industrialisation had increased considerably in the immediate vicinity of the Ayvali Canal between 1996 and 2001. This appears to have resulted in considerable worsening of the pollution problems. The concentrations of heavy metals in the Ayvali canal were remarkably constant over the period studied. However, as the weather was dry throughout the sampling period, and samples were collected at the same time of day and on the same day of the week throughout, this is not really surprising.
It should be stressed that not all of the heavy metals will be present in the solution phase, and some may be associated with colloidal clay or amorphous iron and manganese hydrous oxides. This may be inferred from the concentrations of Fe and Mn present and the water pH. However the purpose of this study was to evaluate the risk of transport of heavy metals to soil via irrigation water, and it would have been inappropriate to exclude these suspended components by membrane filtration of the water samples.

The significantly higher clay content of the irrigated soils may well reflect transport of suspended material to the soil profiles *via* the irrigation water, which might be expected from the observations above about water quality. In the heavily cracked vertisols, such material would be readily moved down the profile with infiltrating irrigation water. However it cannot be stated unequivocally that irrigation is responsible for the higher clay content without further investigation, because spatial heterogeneity between the two groups of soils could also contribute.

Soil pH was also significantly lower in the irrigated soils. This in part probably reflects the acidity of the irrigation water, discussed earlier. This may be a cause for concern, because in the longer term the soil pH will fall and the bioavailability of many heavy metals may increase as a consequence. The significantly lower carbonate concentrations of the irrigated soils indicate that this soil acidification process may already be well under way, and that the buffering capacity of the irrigated soils is finite. Part of the reduction in carbonate concentration as a consequence of irrigation will be attributable simply to the extra water flux passing through the irrigated soils, however. The significantly lower CEC in the irrigated soils may partly reflect the influence of acidification of these soils upon their cation exchange capacity, but mostly is a result of the lower clay content in irrigated soils, which is, in turn, a consequence of silt accumulation in the soil profile. The sediment in the irrigation water was found to be predominantly in the silt size range.

The low C values in the irrigated and non-irrigated soils are due to the high rate of decomposition of organic matter under the prevailing conditions. The higher C and N concentrations in the irrigated soils compared with those in the non-irrigated soils may simply reflect the greater amounts of plant residue being produced as a consequence of irrigation. However the possibility cannot be ruled out that microbial degradation rates of crop residues are being slowed already by the high concentrations of toxic heavy metals in the irrigation water.

The accumulation of heavy metals in the irrigated soils due to a long period of irrigation with polluted water from the Ayvali Canal is readily apparent in Fig. 3. The water results showed that the irrigation water was heavily polluted with industrial waste water or city sewage effluents. Even although the heavy metals may be converted to colloidal suspension form in the Ayvali Canal, in this form they will still be transported to the soil profiles via irrigation water, and accumulate in the soil.

It is interesting to see that even relatively immobile elements such as lead are present at elevated concentrations at 20-40 cm depth in the irrigated profiles (Table 4), and concentrations at depth are not much lower than those at the surface. This almost certainly reflects the ease with which water penetrates to depth in the extensive network of large cracks that characterise these vertisols.

CONCLUSIONS

The results obtained show clearly that industrial wastewater or city sewage effluents seriously pollute the Ayvali Canal irrigation water source. Using this irrigation water is causing soil pollution in the region, both with dissolved and suspended heavy metals. Chemical analyses of soils showed that DTPA-extractable Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn were accumulating in the top soils, with concentrations of the heavy metals being substantially higher in irrigated fields than in non-irrigated fields due to the irrigation with polluted water from the Ayvali Canal. Continued irrigation with polluted water would cause increasing heavy metals accumulation under the semi-arid climate in this region of Turkey.

The irrigation process, through a combination of effects of increased water flux through the soil and acidity of the water, is also reducing the pH and $CaCO_3$ content of the irrigated soils. This appears to be reducing the cation exchange capacity. However the suspended solids in the irrigation water also seem to be increasing the clay content of the irrigated soils, which would also lower CEC.

Carbon and N concentrations increase in response to irrigation, but it is not clear whether this is due to decreased decomposition rate of crop residues in response to pollution in the irrigation water or to increased amounts of crop residue in the irrigated soils.

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