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Evaluation of the Aluminium Content of Acidic Topsoil in the Province of Edirne/Turkey

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Abstract

The naturally circumneutral soils of Edirne Province, Turkey, are acidify with increasing use of ammonium sulfate fertilizers. Soil pH governs both the availability of nutrients and the solubility of Al which becomes toxic to plants when exceeding 1 ppm. The average pH of the soils under wheat/sunflower rotation was 5.11 while average Al, Ca and Mg concentrations were 3.34, 1094.01 and 174.28 ppm, respectively. For over half of the fields, average alumi-num contents of the soils exceeded 1 ppm, the toxicity threshold for plants. Al concentrations were negatively cor-related with pH ($r^2 = -0.402$, $p < 0.0003$). Ca, and Mg concentrations were positively correlated with pH values ($r^2 = 0.320$, $p < 0.0008$; $r^2 = 0.213$, $p < 0.008$, respectively). Ca and Mg, were correlated to Al as a power law with an exponent of 0.25 ($r^2 = 0.293$, $p < 0.001$; $r^2 = 0.557$, $p < 0.0001$, respectively).

Keywords: *Soil acidification; Nitrogen fertilizer; Aluminium*

Introduction

In the clay loam soils of Edirne Province, Turkey, conventional management regimes rely on high N inputs and tillage that may degrade the structural features of the top soil. In these neutral and alkaline reaction soils, cations in soil solution consist of mainly Ca^{+2}, Mg^{+2}, Na^+, K^+. The excessive, ammonium based fertility amendments used in Edirne are known to decrease soil pH. Subsequent dissolution of Al^{+3} and its exchange for base cations on the cation exchange capacity (CEC) facilitates leaching of Ca^{+2} and Mg^{+2}, lowering the buffering capacity of the soil. In Edirne Province, as well as the adjacent provinces in the Thrace Region, the use of ammonium sulfate tripled from 2001 to 2012 (Table 1) and is likely contributing to an accelerated rate of soil acidification. During the same time, yields of wheat and sunflower, which are the province's main crops, have not changed much (4000 kg/ha/year for wheat and 2500 kg/ha/year for sunflower). This mirrors global trends of nitrogen efficiency of grain production where the rate of grain production lags behind fertilizer application [1].

At these low pH values dissolution of iron, aluminum, manganese and boron is favoured. In these kinds of soils, Al toxicity is commonly affecting mainly root growth [2] reducing the uptake of other nutrients. Ritchie [3] & Eyupoglu [4] states that negative effects of low pH on soil fertility also include phosphate precipitation as primary orthophosphate (H_2PO_4) or aluminum phosphates reducing the availability of N and P. Fertility effects at these low pHs are further exacerbated by aluminum toxicity as its concentrations increase to 1-4 mg Mn per kg of soil [5,6]. The purpose of this research was to assess the general acidity status of Edirne soils and to examine the relationship of pH with Ca^{+2}, Mg^{+2} and Al^{3+} contents of acidified agricultural soils representative of Edirne Province.

Year	$(NH_4)_2SO_4$ consumed (tons)	Year	$(NH_4)_2SO_4$ consumed (tons)
2001	8649	2008	23877
2002	8649	2009	29834
2003	9173	2010	27043
2004	14043	2011	28147
2005	19479	2012	27795
2006	22560	2013	28329
2007	17295		

Table 1: *Usage amounts of ammonium sulfate in the province Edirne [7].*

Materials and Methods

Sampling area

Soil samples were taken from 30 randomly selected fields in Edirne Province that had been under a wheat/sunflower rotation for approximately 30 years. This rotation is typical for this region. Most of these soils were on vertisols with a smectite clay mineralogy and were naturally circumneutral.

Soil sampling and analysis

In each field we collected several random samples from the top 20 cm and composited them. The number of samples depended on field size [8]. For the analysis small aliquots were taken from the composited sam-ples. pH was measured with a glass electrode after mixing 1 part of soil with 2.5 parts of water [9]. In soil samples, exchangeable Ca, Mg were measured by flame photometry [10] while Al analysis was made by atomic absorption spectrophotometry [11].

Statistical analysis

Descriptive statistics of sample distribution and correlation coefficients among pH, Ca, Mg and Al of the 30 soil samples were determined with analysis of variance (ANOVA) and Tukey's test were made using Statistical software [12].

Results

Even though the sampling sites were selected from naturally circumneutral soils, summary statistics show that the soils had widely ranging pH, Ca^{+2}, Mg^{+2}, and Al^{+3} values (Table 2, 3). The greatest coefficient of variation (CoV) was for Al^{+3} (143%), the least was for pH (9%). Among the samples, the lowest pH value was 4.29 while the highest value was 6.02. Out of these samples, four ranged between 4.0 - 4.5 and were classed as extreme acidic; nine of them were in extreme severity acidity class; 13 in severe acidity class and 4 were in the class of medium acidity [13].

Property	Mean	Std. Dev.	CoV	Min	Max	95% Confidence Limits	
pH	5.11	0.46	9.0%	4.29	6.02	5.28	4.93
Ca	1093	598	54.7%	190	2516	1317	870
Mg	174	93.1	53.4%	23.0	385	209	139
Al	2.93	4.18	143%	0.02	18.6	1.37	4.48

Table 2: *Statistical summary of sampling distributions of pH, Ca, Mg and Al from soils planted to Sunflower/wheat rotations in Edirne Province. For Ca, Mg and Al concentrations are given in mg/kg.*

Ca concentrations varied between 190 and 2516 mg Ca/kg of soil. The CoV was 55%. Five soil samples belonged to the "quite low" (< 380 mg/kg), 15 were classed as low and 10 were classes as sufficient in Ca. None of the soils had excessive Ca [13-16]. The lowest Mg concentration was 23 mg/kg, the highest concentration was 385 mg/kg. The CoV for Mg was similar to that of Ca.

By FAO classification [14], 3 soil samples were classed as "quite low", 14 as "low" class, and 13 samples as "sufficient" [13-16]. The average of Mg contents of 30 soil samples was 174.28 ppm. Soil Al concentrations varied between 0.15 ppm and 18.64 ppm. The CoV was. In addition, 50% of the fields had Al concentrations greater than 1 mg Al/kg soil, the threshold above which Al is considered to negatively influence crop growth.

X	Y	Model	Intercept	Coefficient	R^2	p
pH	Ca	Linear	-2639	736	0.320	< 0.0008
pH	Mg	Linear	-314	97	0.213	< 0.008
pH	Al	Linear	13.7	-2.36	0.402	< 0.0003
Al	Ca	Y = Ax 0.25 + B	1998	-817	0.293	< 0.0010
Al	Mg	Y = Ax 0.25 + B	364	-117	0.557	< 0.0001

Table 3: *Summary of correlations among pH, Al, Ca and Mg in 30 field soils in Edirne Providence, Turkey.*

pH was linearly correlated to Ca (r^2 =0.320, $p < 0.0008$), Mg (r^2 = 0.213, $p < 0.008$) and Al (r^2 = 0.402, $p < 0.0003$). As is expected for most soils, Ca and Mg decreased while Al concentrations increased as pH decreased. The relationship between Al and the cations Ca and Mg was best described by a power law of the form $Ca = A*Al^{0.25} + B$. The coefficients of this law are given in Table 3. The relationship was asymptotic with the rate of change in Ca and Mg slowing considerably when Al concentrations increased beyond 2 mg/kg (Figure 1).

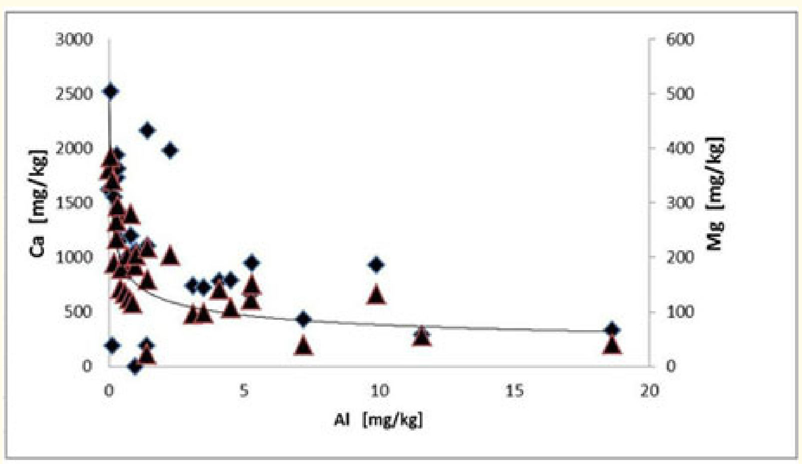

Figure 1: *A Symptotic relationship between Ca, Al, Mg and Al in 30 field soils from Edirne Province, Turkey. Triangles represent Mg and diamonds represent Ca.*

Discussion

The low pH values for the examined soils suggest that acidification of agricultural soils is quite pronounced in Edirne Province. Fertilizer and manure use in Edirne have increased over the past decade (Table 1) while the yields have not significantly increased. Edirne ranks 8th out of 81 provinces in the amount of N fertilizer applied as manure [17]. The finding that Edirne soils are acidifying is supported by estimates that 40% of soils in Edirne require liming [18].

Much of the soil is made up of aluminium silicates whose weathering results in Al release which is likely accelerated by acidification caused by reduced buffering as base cations are exchanged by acid cations (H^+ and Al^{3+}) [19]. In most of the investigated soils Ca^{+2} was "low" to "quite low". These trends match those observed by Klotz and Horst [20], Tok [21], and Tasova and Akın [22]. In the evaluated soils in Edirne, Ca^{+2} and Mg^{+2} concentrations reduced quickly as aluminum concentrations fell towards 2 mg Al/kg soil (Figure 1). Not all the losses of Ca^{+2} and Mg^{+2} should be attributed to leaching. Other mechanisms, such as harvest of a highly fertilized crop might also have depleted the base saturation of the soils. The loss of Ca in particular may have consequences for other indicators of soil health such as earthworms which occur in low abundances in areas where acid deposition has reduced base saturation [23].

Al concentrations can be beneficial to plant growth of between 70-180 µg/kg soil [24,25]. Potentially positive effects on plant potassium uptake of exchangeable Al that occur at low pH [26] may be outweighed by the negative effects of excessive Al availability.

However, levels at which Al is beneficial are well exceeded in the soils studied in Edirne. Among the consequences of increased Al^{+3} concentration are toxicity of Al^{+3} when it is present in excess of 1 mg/kg [21,27], Al^{+3} competes for cation exchange sites with Ca^{+2} and Mg^{+2} and thus may cause leaching of base cations [28] and thus deficiencies in plants, Al^{+3} can bond with PO_4 rendering it unavailable [29]. It is no surprise that PO_4 has been reported as low in the Marmara region in which Edirne is located [22]. Al^{3+} can accumulate in roots inhibiting the uptake of Ca and P [30]. Greater than 50% of the soils in Edirne Province tested by us had Al^{3+} concentrations above the toxicity threshold of 1 mg Al^{+3}/kg of soil which suggest that soils in Edirne Province are acidifying perhaps as a result of overuse of ammonium based fertilizers.

Even though liming is a solution to the apparent acidification problem in Edirne Province, it may not be widely practiced in the region [18]. It may also not be the most sustainable solution as it does not stop overuse of N fertilizers. Reduction in fertilizer applications to match reasonable yield goals would be beneficial to both farm profitability and the environment [31]. Excessive addition of N also occurs in corn production where pressures among farmers result in unreasonable yield goals peer and thus reduced N use efficiency. In addition to the agronomic concerns of acidification, water quality needs to be considered. Increased N-fertilizer applications are well known to cause water quality degradations [31]. Edirne Province is in the Ergene-Meric River watershed where high nitrogen loads come from various sources [32]. Agriculture is contributing approximately 40% of the total N load [33]. Water quality degradations in agricultural water-sheds also affect agriculture as greater need for irrigation arises in this region due to climate change in-duced increases in evapotranspiration and reduced winter precipitation [34].

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