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Nutritional Status of Upland Cotton by Chemical Analysis of Soil and Plant in a Semi-Arid Environment

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Upland cotton (*Gossypium hirsutum* L.) is one of the major agricultural export products of Turkey. This study was carried out in the area of Denizli, a semi-arid environment, which belongs to the Aegean region of Turkey, where cotton is a major crop. Soil and cotton leaf samples (Nazilli 84) were taken from 80 representative cotton fields (two samples from each sampling point) of a total area of 281.3 ha. In the soil samples pH, $CaCO_3$, total soluble salt and some chemical analyses (N, P, K, Ca, Mg, Fe, Zn, Mn and Cu) were carried out. In the leaf samples macro and micro elements N, P, K, Ca, Mg, Fe, Zn, Mn and Cu were analyzed. The results of the soil and leaf analyses were compared in order to determine the nutritional status of the cotton soils and plants and thus to assess the potential of the cotton soils as accurately as possible, which in turn facilitates the possibility to work out specific and appropriate fertilization programs for the region. The soil analyses showed that the soils need 41.3% N, 100% P and 57.5% K fertilization. This result was confirmed by the plant analyses. Regarding micro-elements the soil analyses indicated only Zn deficiency (98.7%), but the leaf analyses also revealed Cu deficiency and showed only partly due to former Zn foliar sprayings Zn deficiency. As high pH and high lime concentrations of the soils can negatively affect the uptake of nutrients, this factor has to be taken into account when preparing fertilization programs and choosing the fertilizer form and type.

Key Words: Cotton, *Gossypium hirsutum* L., Nutrition, Macro and micro elements, Semi-arid environment.

INTRODUCTION

Today cotton is grown in nearly 80 countries of the world. Regarding the area under cotton (689,000 ha) as well as the cotton production (901,000 t) Turkey takes the seventh rank among the cotton-producing countries. In Turkey, cotton is produced on irrigated land. Besides fibres, cottonseeds and press residues are also utilized in Turkey. Nearly 80% of the cotton production is sold in the local market; the remaining part is sold in the world market and represents an important earner of foreign curreny[1].

Cotton is grown in the Mediterranean climate belt of Turkey and is one of the most important crops for this area. In the surroundings of Denizli, one of the major cotton growing area in the basin of the Great Meander which belongs to

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the Aegean region, about 202870 ha land is under cotton. About 40% of the Turkish cotton fields are located in the Aegean region; 9% of them are located in the area of Denizli[1].

High cotton yields depend on many factors such as new and improved varieties, sufficient fertilizing and irrigation, pest control, soil cultivation, etc. One of the main factors to get high yields and a high quality product is an adequate supply with plant nutrients[2,3]. Soil and plant analyses are important prerequisites to prepare fertilizing programs for different cultures and geographical environments; consequently, only corresponding investigation and analysis data make it possible to give proper recommendations regarding time, amount and form of fertilizer applications. Therefore, such investigations are of great importance.

A fertilizing experiment with G. *hirsutum* carried out in the USA showed that for 100 kg of fibre 19.9 kg N ha^{-1} , 5.2 kg P_2O_5 ha^{-1} and 18.4 kg K_2O ha^{-1} were taken up from the soil. In a study carried out in Brazil with the same species, for the production of 2500 kg of seed cotton ha^{-1} , 2960 g Fe ha^{-1} , 250 g Mn ha^{-1}, 116 g Zn ha^{-1}, 120 g Cu ha^{-1} and 320 g B ha^{-1} were taken up from the soil[4]. In Turkey, many investigations regarding physical and chemical properties of soils were carried out in order to improve yield and quality of cotton[5-7]. Earlier studies carried out in the surrounding area of Denizli indicated a lack of microelements. On the other hand, it turned out that on a large scale, the producers only very rarely and randomly apply foliar fertilizer and use unbalanced to high amounts of N fertilizer.

For the present study the chemical properties and the content of macro and micro elements of cotton soil samples were investigated and in addition cotton plant samples were analyzed. The aim of this study was to evaluate these results with the help of the sufficiency ranges and critical limits cited in literature and to compare the results in order to make a contribution to the possibility of preparing more specific and appropriate fertilisation programs for cotton soils of semi-arid environments.

EXPERIMENTAL

The soil and plant samples for this research were sampled from 80 representative cotton fields (two samples from each sampling point, which makes up a total of 160 samples) of a total area of 281.3 ha in the Denizli area in the year 2003. The plant and soil samples were taken during the flowering period as this is the most suitable time to control the nutrient supply of cotton plants in semi-arid regions[5,8]. The third and fourth fully developed leaves under the terminal buds were taken as leaf samples as recommended by Sabbe and Mackenzie[8]. The soil samples were taken from 0–30 cm depths. The leaf samples were taken from the variety Nazilli-84 (Carolina Queen x153-F), a breed of the Nazilli Cotton Research Institute. Nazilli-84 is the most cultivated variety in this area. According to the new soil taxonomy system the investigated soils can be classified as Typic Xerofluvent soils[9]. The weather conditions in the Great Meander Basin are typical for the Mediterranean region, the summers are hot and dry and the winters rainy and mild (total annual precipitation 558 mm over long periods and average annual temperature 15.9°C).

The total N content of the leaves was analysed with a modified Kjeldahl method[10]. In the extracts of the wet acid digested leaves, P was determined with a colorimeter, K and Ca with a flame photometer, Mg, Fe, Zn, Mn and Cu with an atomic absorption spectrometer[10, 11]. The pH of the soil samples was measured according to Jackson[12] and the classification was done according to Kellog[13]. $CaCO_3$ was measured using the Scheibler calcimeter[14] and classification was done according to Aereboe and Falke[15]. Total soluble salts were also determined and classified[16]. The soil texture was ascertained with the hydrometer method[17] and classified according to Black[18]. The total N content of the soils was analysed with a modified Kjeldahl method[19] and the soil classification was done according to the instructions of Kovanci[20]. Available P was determined in water extract[21] and classified according to Güner[22]. In the soil samples the available K, Ca and Mg were extracted with 1 N NH_4OAc; K and Ca concentrations in the extract were measured by flame photometer, but Mg was determined with an atomic absorption spectrometer[23] and classification was done according to the recommendations of Loue[24] and Fawzi and El-Fouly[25]. Fe, Zn, Mn and Cu were extracted with DTPA and measured with an atomic absorption spectrometer[26].

RESULTS AND DISCUSSION

Some chemical properties of the cotton soils

Table-1 shows the results regarding various chemical soil properties (minimum, maximum and mean concentrations), which were investigated in soil samples taken from cotton fields of the Denizli area

TABLE-1
SOME CHEMICAL PROPERTIES OF COTTON SOILS

Soil properties	Min.	Max.	Mean.
pH	7.77	8.22	8.02
Sand (%)	18.00	73.64	34.57
Silt (%)	15.28	72.00	39.13
Clay (%)	4.00	26.14	63.44
$CaCO_3$ (%)	14.84	60.95	27.71
Total soluble salt (%)	0.05	0.31	0.15
Total N(%)	0.03	0.21	0.11
P (mg kg^{-1})	0.50	2.30	0.92
K (mg kg^{-1})	40.00	360.00	177.00
Ca (mg kg^{-1})	1800.00	21000.00	5880.00
Mg (mg kg^{-1})	172.00	1177.00	659.00
Fe (mg kg^{-1})	1.76	27.28	7.49
Zn (mg kg^{-1})	0.12	1.11	0.34
Mn (mg kg^{-1})	5.91	47.85	21.09
Cu (mg kg^{-1})	0.30	2.00	1.07

13.8% of the soils of this area were slightly alkaline and 86.2% moderately alkaline. Regarding the lime ($CaCO_3$) content 12.5% of the soils were highly calcareous and 87.5% very high calcareous. For 59.0% of the soils salinity poses no problem, but 41.0% of the soils show a slight salinity (Table-2). Therefore, in corresponding environments it is necessary to pay attention to the salinity and in particular the irrigation water has to be controlled regularly. Clay loam (26.2%), sifty loam (15.0%) and loam (36.2%) are the predominant soil textures of this area (Table-2). The results of this study show good correspondence with results of previous investigations carried out in the basin of the Great Meander which is representative for semi-arid environments[5, 6]. Cotton grows best on soils with a neutral or slightly alkaline pH[27], but can be grown on a variety of soils from light sandy soil to heavy alluvium and clays. A lime content of 10.0–15.0% is favourable for cotton soils[28]. The results of the study show that except the lime content the analyzed soils are suitable for cotton growing. The lime content exceeds the requirements of cotton; therefore, this factor has to be taken into consideration when fertilizing soils in this environment. Regarding total nitrogen, 7.5% of the soils showed low, 33.8% medium, 41.2% adequate and 17.5% high levels. In general low nitrogen contents were found in soils with a sandy loam texture. Regarding the available phosphorus, 76.3% of the soil samples show a low and 23.7% a medium content of available phosphorus (Table-2). This indicates that in these soils the supply of phosphorus is inadequate for cotton growing. Compared with the other nutrients, the application of phosphorus fertilizers needs a precise knowledge and care regarding technique, depth, form, amount and time of application. As the soils in this region have high lime contents, the application of fertilizers with acidic reaction is appropriate[2, 3].

Regarding the available potassium, 41.2% of the soils have a low, 16.3% a medium, 37.5% an adequate and 5.0% a high level of K. Other studies carried out in the Aegean region showed a similar need for potassium fertilization[5–7]. Regarding the availability of Ca content, 5% of the soils show a medium and 95% an adequately high content. All soils show a sufficient content of available Mg (Table-2). Therefore, no problem exists regarding the Ca and Mg supplies in the soils of this region. With regard to the available Fe, Mn and Cu contents, the results show that the soils have a sufficient supply of these microelements. 86.2% of the analyzed soils show a deficiency of available Zn, 12.5% show a marginal content and only 1.3% an adequate supply of Zn (Table-2). Kirmizi and Atalay[6] found a lack of Zn in 93.3% of the soil samples from the Great Meander basin. In the last years an increasing degree of Zn deficiency was detected in Turkey. Zn plays an important role for the metabolism of plants. Some investigations showed that cotton plants are sensitive to Zn deficiency[3, 29, 30].

Macro and micro element contents of cotton plant samples

The results of leaf analyses (maximum, minimum and mean value) are given in Table-3. The critical N content in cotton leaves during flowering, range according to the different authors is between 3.5 and 4.7%[4, 11, 31, 32]. According to this sufficiency range, 41.3% of the leaf samples showed an inadequate N supply. This result is consistent with the result of the soil analyses, as 41.3% of

TABLE-2
CLASSIFICATION OF COTTON SOILS OF THE DENIZLI AREA BY SOME CHEMICAL SOIL PROPERTIES AND PERCENTAGE OF OCCURRENCE
(0 cm to 30 cm soil depth)

Texture	Clay loam	Silty loam	Clay	Silty clay loam	Loam	Sandy loam	Sandy clay loam
%	26.2	15.0	10.0	1.3	36.2	10.0	1.3
pH 1 : 2.5	Very strongly acid (4.5–5.0)	Strongly acid (5.1–5.5)	Moderately acid (5.6–6.0)	Slightly acid (6.1–6.5)	Neutral (6.6–7.3)	Slightly alkaline (7.4–7.8)	Moderately alkaline (7.9–8.4)
%	0.0	0.0	0.0	0.0	0.0	13.8	86.2
$CaCO_3$ (%)	Weakly calcareous (< 2.5)	Calcareous (2.5–5.0)	Moderately calcareous (5.0–10.0)	Highly calcareous (10.0–20.0)			Very highly calcareous (20.0–50.0)
%	0.0	0.0	0.0	12.5			87.5
Total soluble salt (%)	No effect (< 0.150)	Slightly effective (< 0.150–0.350)	Moderately effective (0.350–0.650)	Highly effective (0.650)			
%	59.0	41.0	0.0	0.0			
Total N (%)	Poor (< 0.05)	Medium (0.05–0.10)	Adequate (0.10–0.15)	High (> 0.15)			
%	7.5	33.8	41.2	17.5			
Available P (mg kg^{-1})	Poor (< 1.30)	Medium (1.30–3.26)	High (> 3.26)				
%	76.3	23.7	0.0				

TABLE 2 (Continued)

Available K (mg kg^{-1})	Poor (< 150)	Medium (150–200)	Adequate (200–300)	High (300–400)	Very high (> 400)
%	41.2	2 16	37.5	5.0	0.0
Available Ca (mg kg^{-1})	Very poor (< 714)	Poor (716–1430)	Medium (1432–2860)	Adequate (>2860)	
%	0.0	0.0	5.0	95.0	
Available Mg (mg kg^{-1})	Poor (< 54)	Medium (54.12–114)	Adequate (> 114)		
%	0.0	0.0	100		
Available Fe (mg kg^{-1})	Deficient (< 0.25)	Marginal (2.5–4.5)	Adequate (> 4.5)		
%	1.3	17.5	81.2		
Available Zn (mg kg^{-1})	Deficient (< 0.5)	Marginal (0.5–1.0)	Adequate (> 1.0)		
%	86.2	12.5	1.3		
Available Zn (mg kg^{-1})	Deficient (< 1.0)	Adequate (> 1.0)			
%	0.0	100			
Available Zn (mg kg^{-1})	Deficient (< 0.2)	Adequate (> 0.2)			
%	0.0	100			

the soil samples showed a low to medium nitrogen content. As 46.2% of the analyzed soils indicated a sandy loam to loamy texture, this result corroborates the statement of Mengel and Kirkby[2] that on light soils the nitrogen fertilization needs special care.

TABLE-3
CONTENTS OF MACRO AND MICRO ELEMENTS OF COTTON LEAVES

Nutrient	Min.	Max.	Mean
N (%)	1.81	4.89	3.69
P (%)	0.04	0.31	0.20
K (%)	0.70	2.94	1.62
Ca (%)	0.56	2.48	1.63
Mg (%)	0.19	1.36	0.77
Fe (mg kg^{-1})	164	2376	423
Zn (mg kg^{-1})	14	126	34
Mn (mg kg^{-1})	32	153	73
Cu (mg kg^{-1})	2	10	6.0

The sufficiency range given for the phosphorus content in cotton leaves range between 0.3–0.5%[4, 11, 31, 32]. If 0.3% is taken as recommended by the cited authors as critical limit to ascertain the phosphorus supply of cotton plants, 96.25% of the investigated leaf samples indicated an insufficient P supply. This result must be seen in connection with the results of the soil analyses, which show on the one hand high pH values and high lime concentrations and on the other hand low contents of available P. Therefore, in this environment, the application of P fertilizers must be planned very specifically and exactly.

The limits given by the different authors regarding the critical potassium content of cotton leaves range between 1.5–3.5%[4, 11, 31, 32]. With regard to this value 61.2% of the leaf samples showed a deficiency of potassium. As 57.5% of the analyzed soils indicated a low to medium supply of potassium, there exists a good agreement with the result of the leaf analyses. According to these results and since cotton is more sensitive to K deficiency than the most other agricultural crops[33], K fertilization must not be neglected in this region. At the same time it must be taken into consideration that many of the soils showed a heavy texture and thus can lead to fixation of potassium.

Regarding the Ca content in cotton leaves Reuter and Robinson[31] recommend 2.25–3.00%, Silvertooth[4] and Mills and Jones[11] 2.00–3.00% as sufficiency ranges. With regard to these values, 91.3% and 76.3% respectively of the leaf samples showed an insufficient content of Ca. Bergmann[32] gives 0.60–1.50% as sufficiency range for Ca. According to these limits, 98.8% of the samples indicated a sufficient calcium supply. This result corresponds with the results of soil analyses, as all soil samples also showed a sufficient Ca content. Therefore, the sufficiency range given by Bergmann[32] seems to be more suitable to assess the calcium supply of cotton plants.

Reuter and Robinson[31] give 0.50–0.90%; Silvertooth[4] and Mills and Jones[11] 0.30–0.90%; Bergmann[32] 0.35–0.80% as sufficiency range for the Mg content of cotton leaves. According to these values 96.3–100% of the samples showed a sufficient Mg content. Since all soil samples also showed a sufficient Mg content, this result suggests that Mg deficiency is no problem for cotton growing in this area.

Under normal conditions an Fe content < 50 mg kg^{-1} in the dry matter of plant samples is assumed to be sufficient[4, 11, 31]. Basing on this criterion the leaf analyses indicated no Fe deficiency. However, it must be always taken into consideration that plants with Fe deficiency symptoms can show the same or even a higher Fe content as plants without the corresponding symptoms[11, 32].

According to the sufficiency ranges given by the different authors for Zn, 25–80 mg kg^{-1} [32] 20–60 mg kg^{-1} [31] and 20–200 mg kg^{-1},[4, 11] 60–87.5% of the investigated cotton plants showed a sufficient Zn supply. This is an opposite result to the soil analysis and can be explained by the fact that 60% of the selected cotton fields were fertilized with zinc sulphate and zinc containing foliar sprays before samples were collected.

Regarding Mn content in cotton leaves, Bergmann[32] gives 35–150 mg kg^{-1}, Reuter and Robinson[31] give 50–350 mg kg^{-1}, Silvertooth[4] gives 25–300 mg kg^{-1} and Mills and Jones[11] give 25–350 mg kg^{-1} as sufficiency ranges. When taking these values into consideration, 93–100% of the leaf samples showed a sufficient Mn content. This result confirms the results of the soil analyses.

The sufficiency ranges for Cu in cotton leaves given by Reuter and Robinson[31], Silvertooth[4] and Mills and Jones[11] lie between 5–25 mg kg^{-1}. When taking these values as a criterion, 41.3% of the analyzed samples showed Cu deficiency. When taking 8–20 mg kg^{-1} as sufficiency range, as recommended by Bergmann[32], 67.5% of the leaf samples indicated Cu deficiency. This different result in comparison to the soil analyses (all soil samples showed sufficient concentrations of available Cu) suggests that the Cu uptake was disturbed by other soil properties. High lime contents and high pH values can reduce the Cu concentration in plants[2, 11].

As overall evaluation of results from data, this study showed that under the semi-arid conditions of the Denizli area, 41.3% of the investigated soils need N, 100% P and 57.5% K fertilization. These results are confirmed by the plant analyses. Since the soils in this region have a high pH and lime content, P fixation must be taken into account. Therefore, for this and other areas with similar soil and climatic conditions, fertilizers with an acidic reaction are preferable. The soil analyses indicated that 98.7% of the soils have Zn deficiency. Due to foliar Zn sprays, leaf samples only partly indicated Zn fertilization requirement. However, as cotton is sensitive to Zn deficiency in this environment, special attention must always be paid to this microelement. Regarding the leaf analyses, a large number of the samples indicated an inadequate Cu supply, although the soil analyses showed no deficiency of available Cu in the studied soils. As the high pH values and the high lime levels of the soils in the region can limit the Zn uptake, Zn and if needed Cu fertilization should preferably be applied as foliar fertilizers in order to avoid the fixation of these microelements. A balanced macro- and micro-

nutrients supply is one of the main factors for high cotton yields. Therefore, when preparing fiiture fertilization programs for cotton fields of this and the corresponding environments, the results of this investigation should be taken into consideration.

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