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Sunflower-nitrogen calibration based on the amount of mineral nitrogen in soil under rainfed conditions in thrace region

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Abstract

Sunflower is grown under both rainfed and irrigated conditions in all regions to meet the vegetable oil needs of Türkiye, however, in the Thrace region, it is the main rotation crop grown under rainfed conditions after wheat. This study was conducted in the Thrace Region between 2013 and 2016 in order to evaluate the parameters that can be used as an index for nitrogen fertilization recommendations for sunflower plant. For this purpose, organic matter and saturation were determined in soil samples taken from 0-20 cm depth before the experiment and ammonium and nitrate contents were determined in soil samples taken from 0-30 cm, 30-60 cm, and 60-90 cm depths. Within the scope of the study, 27 field trials were conducted over four years. Nitrogen levels of 0 (control), 3, 6, 9, and 12 kg da^{-1} were implemented in the trials conducted in a Latin square experimental design. In this study, $log (279.9-y) = log279.9-0.090b_1-0.117x$ Mitscherlich calibration equations were determined based on 0-30 cm ammonium+nitrate content in the soil.

Introduction

Soils naturally have different yield potential, which is related to the mineral matter and organic matter content of the soil. Soil texture and organic matter are two important factors affecting water retention capacity. Organic matter is an important source of nitrogen as well as having important effects on water holding capacity. However, since the properties of soils vary according to their parent material and formation conditions, the yield and fertilizer requirements are also different. The amount of mineral nitrogen forms in the soil is influenced by organic matter, the previous plant in rotation, the amount of nitrogen fertilizer applied, drought or humidity, and the addition of plant residues to the soil. In a dryland farming system, dry periods after N fertilization applied to the previous crop can cause an excess of N, which reduces N use efficiency (Angaás et al., 2006).

More than half of the sunflower cultivation in Türkiye is in the Thrace Region, where rainfall-dependent cereal-sunflower alternation is practiced in ¾ of the agricultural lands. Soil analysis laboratories, which provide soil analysis services for farmers, take the results of soil analysis as a basis for phosphorus and potassium fertilization recommendations, while the amount of organic matter in the soil is taken into account in nitrogen fertilization recommendations (Güçdemir, 2006), but the main factor determining the recommendation is the results of local nitrogen fertilization trials. The data obtained from these experiments cause contradictory results. (Arslan, 1989) obtained the quadratic equation $Y = 143.95+37.793x-$

$1.929x^2$ for the relationship between sunflower yield and nitrogen fertilizer in a study carried out to determine the nitrogen fertilizer requirement of sunflower under rainfed conditions in the Thrace Region and determined that 90 kg ha^{-1} N should be applied for the economic optimum yield according to 1987 fertilizer-crop prices. In a similar study in Edirne province, Süzer (1998), stated that the equation $[Y = 1.988+4.86x-0.032x^2$ $(R = 0.804^{**})]$ can be used to determine the nitrogen fertilizer requirement of sunflower. Considering the year 1997, fertilizer, and crop prices, the economic optimum fertilizer level was determined as 50 kg ha^{-1} N. Studies have reported that the amount of NO_3^-N can be taken into account instead of the amount of soil organic matter in determining the nitrogen need of plants (Korkmaz et al., 2021; Gokmen Yilmaz et al., 2021). Besides mineral nitrogen forms, there are other chemical methods to determine the soil's capacity to provide nitrogen to plants. In studies conducted in the dry farming areas of Central Anatolia, it was determined that the phosphate-borate buffer method and the acid $KMnO_4$ method were the best methods, and the total hydrolyzable ammonium content showed a strong correlation with biological methods (Elkarim and Usta, 2001).

Ayla (1984) applied nitrogen (0, 6, and 12 kg N da^{-1}) before sowing in 1974-1977 in a study conducted to determine the water consumption, amount, time, and number of irrigation water and nitrogen-water relations of sunflower under Central Anatolian conditions. As a result of the study, at 6 kg da^{-1} nitrogen implementation, when 5% of the available capacity was reached, 640 mm irrigation water was applied 5 times from sowing to harvest and the annual water consumption of the plant was 815 mm and the highest daily water consumption was determined in July with 11.79 mm. In this case, 235 kg da^{-1} yield was obtained, while 226 kg da^{-1} yield was obtained in the implementation with no fertilizer at the same irrigation amount. At 12 kg da^{-1} nitrogen level, 235.5 kg yield was obtained. This indicates that the addition of nitrogen fertilizer does not cause a very significant increase in sunflower yield increase when the water requirement of the plant is met.

Currently, nitrogen recommendations for most states, such as North Dakota, South Dakota, Nebraska, and Kansas, are based on expected yield formulas. The formulas include a reduction in nitrogen recommendations due to nitrate content in the soil, organic matter level, fertilization, and gains from the previous crop. The formula is expected yield per decare x 0.05. However, when recent nitrogen rate studies were evaluated, yields responded less than expected to nitrogen in other countries (Darby et al., 2013; Scheiner et al., 2002).

In a study investigating the effects of environmental conditions (temperature, rainfall) and nitrogen applications on sunflower phenological indicators and water use efficiency in at two locations in Mexico, plant growth, yield and yield components, and water use efficiency were significantly affected by environment, nitrogen application and environment-nitrogen interaction. Nitrogen positively affected other traits (Olalde et al., 2001).

Considering the amount of nitrogen removed from the soil by plants, Chapman (1960) stated that if the amount of NO_3^-N in the soil for plants is less than 5 mg kg^{-1}, it is deficient, and if it is more than 20 mg kg^{-1}, it is high.

Mortvedt et al., (1996) stated that the amount of nitrogen fertilizer to be applied should be determined by taking into account the expected sunflower yield for each field. The researchers published a table in which the amount of nitrogen to be applied can be determined according to the amount of nitrate and organic matter in the soil based on the expected yield.

Kansas State University, in their report, interpretation of soil analysis results and fertilization recommendations, it is accepted that 1% of the organic matter of the soil will provide mineralized nitrogen for the expected crop yield of sunflower and other crops grown in summer. The nitrogen requirement of the plant is determined by taking into account the previous crop in the rotation and the amount of nitrate in the soil and irrigation water (Meyer, 1997). The formula used for this purpose is given below.

N Rec^{2*} = (Yield Goal × 0.075) - (% SOM × 20) - Profile N - Manure N - Other N Adjustments + Previous Crop Adjustments

*2: It will be useful to give 3.5 kg ha^{-1} of nitrogen in the early period for adequate development of the plants.

Gürbüz and Kardeş (2017) applied 0 (control), 3, 6, 9 and 12 kg da^{-1} (N) levels in Thrace Region in order to investigate the parameters that can be used as an index in nitrogen fertilization recommendations for sunflower plants. Correlation coefficient between nitrogen requirement and the amount of soil organic matter was 0.72, the correlation coefficient for saturation was 0.63, the correlation coefficient for 0-30 cm nitrate nitrogen was 0.62, the correlation coefficient for ammonium+nitrate content in 0-30 cm was 0.71 and correlation coefficient for ammonium+nitrate content in 0-60 cm was 0.72.

It has been reported that the Mitscherlich-Bray equation $[\log(A\text{-}y) = \log A - c_1 b_1 - c_x]$ can be used for the Mitsherlich calibration equation, depending on the relationships between the KCl-extractable NO_3-N content in the soil and the yield (Bray, 1945; Afzal et al., 2014, Sonar and Babhulkar, 2002, Ali et al., 2022). In this study, it was aimed to obtain the relationship between the amount of $NH_4^+NO_3^-$N extracted with KCl and the yield for the sunflower plant under rainfed conditions in Thrace Region, using the Mitscherlich-Bray equation.

Materials and Methods

Thrace Region, located in the northwest of Turkey, has an area of 2 372 000 ha and constitutes 3.1% of the total area of Türkiye. In the region, the wide flat lands between the Istranca and Ganos Mountains, forming the partially undulating Thracian peneplain, are largely suitable for agriculture (Anonymous, 1971).

Although the region is characterized by different climate types, Edirne, Tekirdağ and Kırklareli are characterized by a continental climate. This climate is characterized by hot and dry summers and cold and rainy winters Some meteorological data of these three provinces where the experiments were carried out as the average of long years are given in Table 1 (Anonymus, 2024c; Anonymus, 2024d; Anonymus, 2024e).

Table 1. Some meteorological data of the provinces in Thrace

Province	Period	Annual precipitation mm	Average temperature °C	Highest temperature °C	Lowest temperature °C
Edirne	1930-2023	601.0	13.8	44.1	-19.5
Kırklareli	1959-2023	583.7	13.3	42.5	-15.8
Tekirdağ	1940-2023	580.0	14,1	40.2	-13.5

The month with the highest rainfall is December and the month with the lowest rainfall is August. The number of frost days in the region is between 30-90. The prevailing winds are the northeaster and the stellar and the average wind speed is 2.6 m s^{-1}.

In the study, the experimental areas were distributed to Kırklareli, Edirne and Tekirdağ considering major soil groups and especially different soil textures. Trial locations were determined as Kırklareli, Pınarhisar, Kaynarca, Lüleburgaz (Sarmısaklı Farm), Edirne, Orhaniye (Keşan), Boztepe (Keşan), Tekirdağ, Çorlu (Velimeşe), Hayrabolu (Figure 1).

Figure 1. Locations of the trial areas

In the trials, the Tunca variety, which is intensively cultivated in the region due to its resistance to orobanche and high oil content, was used as sunflower plant. Ammonium nitrate fertilizer containing 33% N was used for nitrogen fertilization during seeding and top fertilization.

The field trials were conducted under rainfed conditions and N_0=0, N_1=3 kg da^{-1} N, N_2=6 kg da^{-1} N, N_3=9 kg da^{-1} N, N_4=12 kg da^{-1} N levels were applied as nitrogen fertilizer. Ammonium nitrate fertilizer containing 33% N was applied at planting (1/2) and top dressing (1/2). No microelement fertilization was applied to the sunflower plant in the trials. The experiment was conducted in a Latin square experimental design with 5 replications (Yurtsever, 1984). The plot size was 5.6x7=39.2 m^2 at planting and 2.8x5=14 m^2 at harvest. A gap of 1.0 m was left between the plots. For sunflower planting, the seedbed was plowed in the fall after the wheat harvest and made ready for planting by harrowing in the spring. In all treatments, half of the nitrogen fertilizer was applied before planting and the other half before hoeing.

Soil and Plant Analysis Methods

Before planting, soil samples were taken from 0-20 cm depth for fertility analysis and 0-30, 30-60, and 60-90 cm depths with a soil auger in order to determine mineral nitrogen forms.

Saturation (%) was determined by saturating the soil with water, soil reaction (pH) was measured by using a pH meter in water-saturated soil (Jackson, 1958), Electrical conductivity (EC) was measured with an EC meter in soil-water suspension (Richards, 1954), Lime (%) determined by the Scheibler Calcimeter method (Tüzüner, 1990), Organic matter (%) determined by the Modified Walkley-Black Method (Tüzüner, 1990). Available phosphorus was determined by sodium bicarbonate method (Olsen, 1954), available potassium determined by ammonium acetate method (Tüzüner, 1990), available boron (B) for plants was extracted according to Berger and Troug (1939) and determined by Spectro Arcos SOP ICP-OES device (Kacar, 2009), available manganese, iron, copper and zinc for plants determined by DTPA extraction method and determined by Spectro Arcos SOP ICP-OES (Lindsay and Norvell, 1982).

Table 2. Soil analysis results of the trial areas

Year	Location	Sat. %	pH	EC %	Lime %	OM %	Contents of plant available nutrients						
							P_2O_5 kg da^{-1}	K_2O kg da^{-1}	B mg kg^{-1}	Mn mg kg^{-1}	Fe mg kg^{-1}	Cu mg kg^{-1}	Zn mg kg^{-1}
2013	Kırklareli	64	7.44	0.03	17.5	0.83	8.49	53.0	0.50	21.59	7.83	5.49	1.95
	Edirne	29	4.60	0.02	0.0	0.99	22.07	46.5	0.51	110.6	66.44	2.16	1.19
	Tekirdağ	53	7.50	0.06	9.0	1.57	4.86	86.0	0.53	12.56	7.28	9.05	0.63
	Boztepe	99	7.50	0.07	1.0	0.54	8.93	86.0	0.52	14.57	7.50	1.08	0.57
	Sarımsaklı	63	7.54	0.09	5.5	1.07	11.47	146.0	0.68	10.44	7.90	1.60	0.29
	Pınarhisar	46	7.44	0.06	13.5	1.65	8.93	95.0	0.49	19.58	9.02	2.06	0.32
2014	Kırklareli	49	7.55	0.02	5.78	1.33	15.70	76.65	0.82	7.19	4.70	3.54	1.07
	Edirne	45	5.60	0.03	0.0	0.96	22.20	56.90	0.44	79.39	33.90	1.72	0.57
	Tekirdağ	59	7.74	0.04	6.80	0.87	7.21	29.07	0.43	2.17	3.36	3.16	0.15
	Keşan	64	7.56	0.06	5.44	1.45	11.33	93.98	0.68	6.84	5.42	0.93	0.34
	Sarımsaklı	89	7.82	0.08	6.20	1.49	10.10	137.1	1.56	8.19	9.26	1.15	0.19
	Pınarhisar	65	7.23	0.06	0.0	1.23	12.01	98.71	1.25	15.02	7.40	1.48	0.26
2015	Kırklareli	51	7.79	0.042	17.5	1.22	9.65	54.85	0.72	22.35	6.02	4.36	1.26
	Edirne	39	5.46	0.028	0.2	0.48	27.40	68.75	0.46	136.9	29.47	1.83	0.88
	Tekirdağ	57	7.51	0.053	15.0	0.77	9.12	92.00	0.71	11.02	8.20	11.1	0.46
	Keşan	66	7.59	0.063	3.7	1.54	11.40	101.5	0.65	27.50	12.28	2.00	0.39
	Sarımsaklı	64	7.41	0.086	7.5	1.05	16.00	115.5	0.86	11.29	8.67	1.36	0.38
	Pınarhisar	75	7.33	0.074	5.5	1.46	7.52	123.3	0.67	16.87	5.97	1.80	0.37
	Kaynarca	50	4.82	0.013	-	0.65	18.20	31.30	0.27	68.24	29.76	0.58	0.44
	Velimeşe	38	5.09	0.007	-	0.33	22.80	37.10	0.22	73.60	23.27	0.72	0.57
	Boztepe	61	7.43	0.068	5.5	1.03	12.54	57.10	0.56	17.48	7.35	0.90	0.52
	Hayrabolu	55	4.69	0.016	-	0.91	33.10	46.20	0.42	104.7	69.64	1.46	0.37
2016	Kırklareli	42	7.60	0.018	38	1.42	17.10	39.8	0.66	9.28	4.88	4.52	4.20
	Edirne	39	5.46	0.017	0.0	0.49	18.60	37.4	0.32	37.8	30.92	1.56	0.66
	Tekirdağ	57	7.83	0.043	17.5	1.02	11.30	42.8	0.64	7.68	10.4	5.4	0.41
	Keşan	58	7.85	0.041	9.0	1.93	10.10	60.0	0.68	15.08	7.52	1.98	2.34
	Pınarhisar	63	7.77	0.042	53	1.52	13.70	44.3	0.40	20.92	4.52	2.02	0.60

Soil samples were air-dried in the shade and sieved through a 2 mm sieve for inorganic nitrogen ($NH_4^+NO_3^-N$) analysis as stated by Bremner (1965). Then, 10 g of soil sample for analysis was placed in a 250 ml Erlenmeyer and 100 ml of 2M KCl (1/10 ratio) was added. The flask was sealed with a rubber stopper and shaken for 1 hour and waited for about half an hour until the soil settled to the bottom. The ammonium and nitrate nitrogen amounts were determined by distillation method by taking 30 ml of the upper clear liquid. For $NH_4^+NO_3^-N$, 0.2 g MgO and 0.2 g Devarda alloy were added to the extract. Then 30 ml of the extract was taken and 0.2 g MgO was added to determine NH_4-N nitrogen. The amount of NO_3-N is determined by subtracting NH_4-N from $NH_4^+NO_3^-N$. The amount of nitrite was neglected due to very low content in soils (Bremner, 1965).

Nitrogen Fertilization Calibration Based on the Amount of Mineral Nitrogen in Soil

The Mitscherlich equation "$\log (A-Y) = \log A - c_1 b_1 - c_x$" modified by Bray (Yurtsever, 1969) was used for the collective evaluation of nitrogen fertilizer trials, and c_1 values were found for soil nitrogen (b_1) and c values were found for fertilizer nitrogen (x_1+x_2) x represents N levels.

Calculation of the Maximum Yield

The equation "$A = \frac{Y_k - Y_0}{k-1}$" was used to determine the amount of N that should be supplied to the soil in order to reach different levels of maximum yield (90%, 92%, 94%, 96%, 98%). The calculation methods of calibration values can be briefly summarized as follows.

a) Calculation of the Impact Value of Soil Nitrogen (c_1)

By using the equation log(A-Y_0) = logA-c_1b_1, c_1 was calculated for each trial.

*The average yield of the plots with the highest yield (9 kg da^{-1} N application) is A, the average yield of the control plots is Y_0, the soil analysis value is b_1

b) Calculation of the Impact Value of Fertilizer Nitrogen (c)

By using the equation log (A-Y) = log A-c_1b_1-c_x, c was calculated for each trial.

By the formulas given above, c_1 and c values were calculated for each trial and nitrogen level, their averages were taken and c_1 and c values were obtained for sunflower grown in the climate and soil conditions of the Thrace region.

c) Calculation of Maximum Yield

The formula "$\boldsymbol{A = \frac{Y_k - Y_0}{k-1}}$" was used.

A = Maximum yield

Y_0 = Yield of control plot

Y = Average crop yield for each nitrogen level

k = antilogarithm of cx

x = Nitrogen dose

c = Effect value of fertilizer nitrogen

Maximum yield is found for different nitrogen levels (x_1, x_2) in each trial and evaluated by taking the average.

d) Calculation of Baule Units

One baule unit of nutrient (nitrogen) increases yield by 50% of the difference between the present yield and maximum possible yield. Baule unit for soil nitrogen is obtained by solving the equation *log (A-Y_0)=log A - c_1b_1* in terms of b, by substituting 100 for maximum yield A, 50 for Y_0, and the calculated average value for c_1.

Baule unit of fertilizer nitrogen is obtained by the equation log (A - Y_0) = log A - c_x, by substituting 100 for maximum yield A, 50 for Y_0, and the calculated average value for c.

e) Determination of Crop %

The ratio of other nitrogen levels to the highest nitrogen level is determined and multiplied by 100. The smaller the % values, the higher the nitrogen requirement.

Crop%= (Y_0/Y_3) x 100

Y_0: Sunflower yield obtained in control

Y_3: Sunflower yield obtained in x_3 (the highest average yield)

f) Classification of Sufficiency Percent in Terms of Nitrogen Content of Soil

In the equation log (100-Y_0) = log100-c_1b_1, the previously known value of c_1 was substituted and Y_0 is found by giving b_1 increasing values starting from 2. This value has been determined based on the consideration that significant results can be obtained from every additional 2 kg ha^{-1} of N in the soil, taking into account the NH_4+NO_3 amount in the trial soils (3.95-21.8 kg da^{-1}).

g) Determination of the amount of nitrogen to be applied

By substituting the previously determined parameters b_1, c_1, c_1, and c in the equation log (100-Y_0) = log100-c_1b_1-c_x, the amount of nitrogen (x) to be applied for the targeted levels of maximum yield (such as 90%, 92%, ... 98%) for the parameter Y_0 was calculated by substituting the previously determined parameters b_1, c_1, and c. The 20 kg da^{-1} NH_4+NO_3-N in the soil, which is determined in Boule units and is sufficient to take more than 98% of the crop, a classification was made for sunflower by dividing into five parts (0-4), (4-8), (8-12), (12-16) and (16-20).

h) Calculation of Economic Fertilizer Amount

Mitscherlich equation was used and the theoretical maximum product level of all trials was used for A in the equation, c_1, b_1, and c parameter values were substituted and fertilizer levels such as 1, 2, 3, 4 ... were written for x and Y values were determined for each fertilizer level. To perform the economic analysis, both marginal product and marginal fertilizer amounts were determined by using the current fertilizer marginal revenue values.

Results and Discussion

Soil Characteristics of the Experimental Area

In this study, 6 field trials were conducted in 2013, 6 in 2014, 10 in 2015, and 5 in 2016 in Thrace Region. The analysis results of soil samples taken from 0-20 cm depth before sowing were given in Table 3.

While the results of all trials were used in determining the relationships between soil parameters and nitrogen fertilizer requirements of sunflower, the results of the trials in which the effect of nitrogen fertilization on crop yield was statistically significant at 5% and 1% levels were taken into account in calibration calculations. Regression was used to investigate the correlation and the results of the experiments with significance levels of 5% and 1% were used.

Mineral nitrogen contents in the trial areas

The $NH_4^+NO_3^-N$ and NO_3^-N contents of soil samples taken from different depths from the experimental areas are given in Table 4. It is preferred to determine sunflower yield based on $NH_4^+NO_3^-N$ rather than solely NO_3-N, as it is expected that NH_4-N determined in samples taken before planting will undergo nitrification shortly and turn into NO_3-N.

Table 3. Results of mineral nitrogen contents of trial areas

Location	Soil depth, cm	2013	2014	2015	2016
		$NH_4^+NO_3^-N$, mg kg^{-1}			
Kırklareli	0-30	10.15	10.5	22.61	33.95
	30-60	12.25	8.7	19.67	20.65
	60-90	14	9.6	14.07	16.45
Edirne	0-30	18.55	14.8	20.37	36.4
	30-60	9.1	15.7	12.95	21
	60-90	9.8	14.8	11.2	15.4
Tekirdağ	0-30	18.2	15.7	18.2	25.2
	30-60	30.8	13.1	19.6	25.55
	60-90	19.6	13.1	18.41	16.45
Keşan	0-30	24.15	35.75	21.35	34.65
	30-60	25.55	20.12	16.45	29.4
	60-90	20.3	19.2	16.1	25.9
Sarımsaklı	0-30	23.45	16.6	24.92	
	30-60	13.3	13.1	18.55	
	60-90	10.85	11.3	16.94	
Pınarhisar	0-30	30.45	19.2	20.58	58.1
	30-60	10.5	20.1	16.17	26.95
	60-90	19.25	17.5	14.35	25.9
Kaynarca	0-30			22.61	
	30-60			15.33	
	60-90			12.81	
Velimeşe	0-30			21.21	
	30-60			18.62	
	60-90			15.05	
Boztepe	0-30			19.53	
	30-60			14.07	
	60-90			13.44	
Hayrabolu	0-30			15.89	
	30-60			20.44	
	60-90			12.67	

Table 4. Sunflower crop yield, soil $NH_4^+NO_3^-N$ contents and Y_3 and % yield increase

Trials	$NH_4^+NO_3^-N$ (0-30cm)		Applied nitrogen, kg da^{-1}					Yield Increase (%) with Y_3*
			0	3	6	9	12	
			Yield, kg da^{-1}					
	mg kg^{-1}	kg da^{-1}	Y_0	Y_1	Y_2	Y_3	Y_4	
Ed-13	18.56	6.96	216	228	252	266	252	23.15
Tek-13	18.20	6.83	302	337	355	355	352	17.55
Kırk-14	10.52	3.95	155	176	205	240	208	54.84
Ed-14	14.80	5.55	242	261	283	299	289	23.55
Tek-14	15.72	5.90	147	155	190	184	174	25.17
Kırk-15	21.36	8.01	185	215	240	251	258	35.68
Ed-15	20.36	7.64	141	155	161	166	167	17.73
Tek-15	18.20	6.83	221	232	326	371	384	67.87
Keş-15	21.36	8.01	265	299	330	325	321	22.64
Sar-15	24.92	9.35	221	231	255	255	251	15.38
Pın-15	20.60	7.73	208	239	245	243	242	16.83
Kay-15	22.60	8.48	108	130	152	137	133	26.85
Vel-15	21.20	7.95	173	187	196	202	197	16.76
Boz-15	19.52	7.32	173	193	206	225	253	30.06
Tek-16	25.20	9.45	246	283	289	302	271	22.76
Kırk-16	33.96	12.74	190	265	244	213	201	12.11
Edir-16	36.40	13.65	241	280	270	265	262	9.96
Pın-16	58.12	21.80	239	284	286	265	256	10.88
Keş-16	34.64	12.99	185	262	238	242	226	30.81
			203	232	249	253	247	

*: Calibration calculations were made assuming 375 tons of soil in a decare of 0-30 cm depth.

Sunflower-Nitrogen Calibration Based on the Amount of Mineral Nitrogen in Soil

Sunflower-Nitrogen Calibration by Ammonium+Nitrate Content (0-30 cm depth)

In this study, calibration calculations were made based on the total amount of ammonium and nitrate in the soil at 0-30 cm depth before sunflower planting (Table 3). In Table 4, $NH_4^+NO_3^-N$ at 0-30 cm depth was converted from mg kg^{-1} to kg da^{-1}. In this conversion, 1 da soil was accepted as 375 tons. According to the results of variance analysis, the average yield values of the trials in which the effect of nitrogen was significant were taken and Y_3 and % yield increase were calculated and given in Table 4. The reason for taking Y_3 here is that maximum yield was reached at the N_3 fertilizer level in most of the trials and yield decreased at the N_4 level. In the calculation of % yield from Y_0 to Y_3; % yield increase = $100*(Y_3-Y_0) / Y_0$ equation was used.

The data obtained as a result of the calculation of percent (%) crop values and Mitscherlich constants are given in Table 6. The relationship between the increases in yield with nitrogen fertilization relative to Y_3 and soil analysis values (kg da^{-1}) at 0-30 cm is shown in Figure 2.

Table 6. Baule units of $NH_4^+NO_3^-N$ amount in soil and fertilizer for sunflower

Baule Units	Sufficiency %	Soil (0-30 cm) $NH_4^+NO_3^-N$, kg da^{-1}	Fertilizer (applied) $NH_4^+NO_3^-N$, kg da^{-1}
1	50.0	3.33	2.58
2	75.0	6.67	5.16
3	87.5	10.00	7.75
4	93.4	13.34	10.33
5	96.9	16.67	12.91
6	98.4	20.01	15.49
7	99.2	23.34	18.08
8	99.6	26.68	20.66
9	99.8	30.01	23.24
10	99.9	33.35	25.82

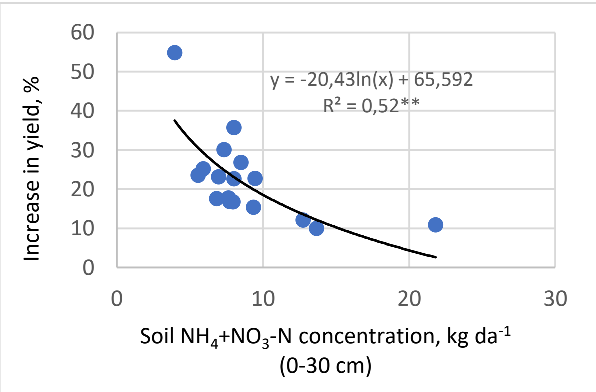

Figure 2. Relationship between increases in sunflower yield and the content of $NH_4^+NO_3^-N$ in the soil (0-30 cm)

Baule units (x) for ammonium+nitrate nitrogen in soil and fertilizer were calculated and given in Table 6. The calibration curve of ammonium+nitrate content at 0-30 cm soil depth for sunflower is given in Figure 3.

Based on the $NH_4^+NO_3$ nitrogen content in the soil at 0-30 cm, the nitrogen fertilizer demand of sunflower was determined by the formula log(A-y)= log A-c1b1-cx. The data obtained for sunflower with this formula are shown in Table 7 and the calibration curve is shown in Figure 4.

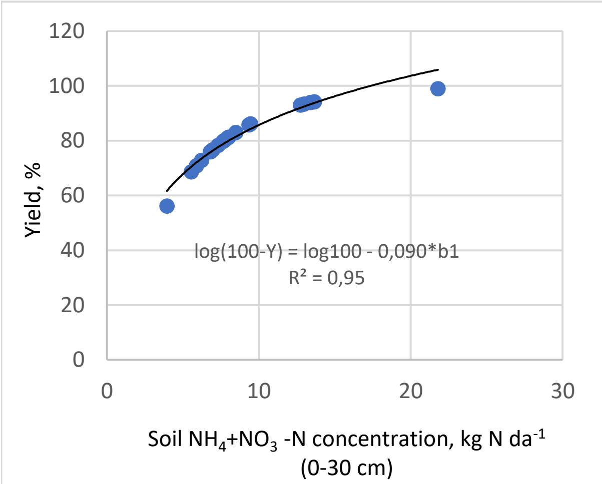

Figure 3. Calibration curve of $NH_4^+NO_3^-N$ content at 0-30 cm depth for sunflower

Economic Fertilizer Levels

The amount of nitrogen fertilizer to be applied to sunflower under rainfed conditions in the Thrace Region will depend on the amount of $NH_4^+NO_3^-N$ in the soil, the targeted yield percentage and the economic feasibility of the fertilizer to be applied. As can be seen from Table 8, as the amount of nitrogen in the soil increases, the amount of nitrogen to be applied will decrease depending on the amount of yield % targeted to be obtained. In this study, total and marginal crop yields were obtained at very low, low, medium, adequate, and high (4, 8, 12, 16, and 20) levels for different soil nitrogen contents by using the *log279,9-0,090b1-0,117x* functional equation (Table 8).

After determining the fertilizer-product relationships as above, it is possible to determine the economic fertilizer levels from fertilizer and crop-price relationships. For this purpose, the marginal crop amounts and marginal fertilizer amounts and their TL values are given in Table 9 (the price per kg of 33% ammonium nitrate fertilizer used in the trials for four years in 2016 was 0.85 TL (Anonymous, 2024a) and the price per kg of sunflower containing 40% oil was 1.7 TL (Anonymous, 2024b).

Table 5. Sunflower yield (%) and Mitscherlich constants with different amounts of nitrogen application

Trials	$NH_4^+NO_3$ kg da^{-1} (0-30cm)	Applied nitrogen, kg da^{-1}					Mitscherlich constants			
		X_0 Control	X_1 3	X_2 6	X_3 9	X_4 12				
		Yield, %					c_1 for b_1	c for X_1	c for X_2	Theoretical maximum yield
		Y_0	Y_1	Y_2	Y_3	Y_4				
Ed-13	6.96	81.22	85.81	94.66	100	94.66	0.104	0.040	0.090	293.1
Tek-13	6.83	85.06	94.98	99.94	100	99.21	0.121	0.157	0.354	383.7
Kırk-14	3.95	64.58	73.33	85.42	100	86.67	0.114	0.041	0.064	285.8
Ed-14	5.55	80.94	87.29	94.65	100	96.66	0.130	0.059	0.092	329.7
Tek-14	5.90	79.89	84.24	103.26	100	94.57	0.118	0.035		203.9
Kırk-15	8.01	73.71	85.66	95.62	100	102.79	0.072	0.088	0.130	286.6
Ed-15	7.64	84.94	93.37	96.99	100	100.60	0.108	0.119	0.116	179.5
Tek-15	6.83	59.57	62.53	87.87	100	103.50	0.058	0.011	0.087	451.8
Keş-15	8.01	81.54	92.00	101.54	100	98.77	0.092	0.121		357.3
Sar-15	9.35	86.67	90.59	100.00	100	98.43	0.094	0.050		273.3
Pın-15	7.73	85.60	98.35	100.82	100	99.59	0.109	0.314		261.9
Kay-15	8.48	78.83	94.89	110.95	100	97.08	0.080	0.206		152.6
Vel-15	7.95	85.64	92.57	97.03	100	97.52	0.106	0.095	0.114	217.6
Boz-15	7.32	76.89	85.78	91.56	100	112.44	0.087	0.070	0.073	253.0
Tek-16	9.45	81.46	93.71	95.70	101	89.74	0.077	0.156	0.106	332.2
Kırk-16	12.74	89.20	124.41	114.55	102	94.37	0.076			225.4
Edir-16	13.65	90.94	105.66	101.89	103	98.87	0.076			277.9
Pın-16	21.8	90.19	107.17	107.92	104	96.60	0.046			279.0
Keş-16	12.99	76.45	108.26	98.35	105	93.39	0.048		0.192	272.7
Average (c_1 and yield)							0.090	0.104	0.129	279.9
Average (x)								0.117		

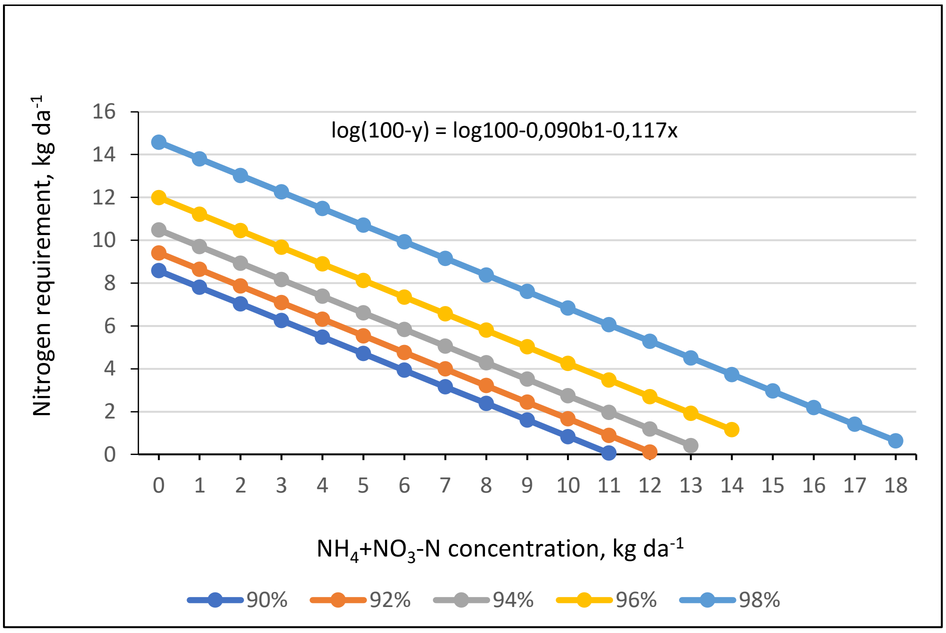

Figure 4. The relationship between the content of $NH_4^+NO_3^-N$ (kg da^{-1}) in the 0-30 cm soil depth and the nitrogen requirement of sunflower grown under rainfed conditions.

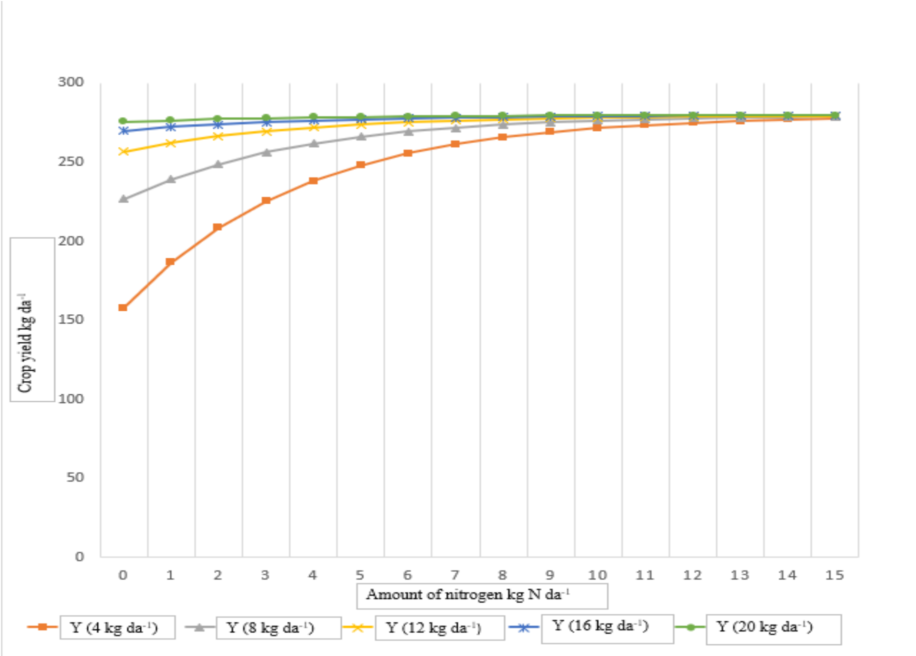

Figure 5. Relationship between nitrogen (NH_4+NO_3-N) content and sunflower yield under rainfed conditions

Table 7. Nitrogen amounts to be given to sunflower grown under rainfed conditions for different yield levels depending on the amount of $NH_4^+NO_3^-N$ in the soil (0-30 cm)

$NH_4^+NO_3^-N$ kg da-1	Crop, %	Maximum crop percentage				
		90,%	92,%	94,%	96,%	98,%
		Amount of Nitrogen Required, kg da-1				
1	18.77	7.80	8.63	9.71	11.22	13.80
2	34.01	7.03	7.86	8.93	10.44	13.02
3	46.40	6.25	7.09	8.16	9.67	12.25
4	56.46	5.48	6.31	7.38	8.89	11.48
5	64.63	4.71	5.54	6.61	8.12	10.70
6	71.27	3.93	4.76	5.84	7.35	9.93
7	76.66	3.16	3.99	5.06	6.57	9.15
8	81.04	2.38	3.21	4.29	5.80	8.38
9	84.60	1.61	2.44	3.51	5.02	7.60
10	87.49	0.83	1.67	2.74	4.25	6.83
11	89.84	0.06	0.89	1.96	3.47	6.06
12	91.74		0.12	1.19	2.70	5.28
13	93.29			0.41	1.93	4.51
14	94.55				1.15	3.73
15	95.57				0.38	2.96
16	96.40					2.18
17	97.08					1.41
18	97.63					0.64
19	98.07					
20	98.43					

Table 8. Total and marginal yields for sunflower

N kg da^{-1}	NH_4+NO_3-N marginal quantity	N kg da1 (AN 33%)	b_1=4 kg da^{-1} very low		b_1= 8 kg da^{-1} low		b_1= 12 kg da^{-1} medium		b_1=16 kg da^{-1} adequate		b_1=20 kg da^{-1} high	
			Total crop kg da^{-1}	Marginal crop kg da^{-1}	Total crop kg da^{-1}	Marginal crop kg da^{-1}	Total crop kg da^{-1}	Marginal crop kg da^{-1}	Total crop kg da^{-1}	Marginal crop kg da^{-1}	Total crop kg da^{-1}	Marginal crop kg da^{-1}
0	1	3.33	157.99		226.79		256.75		269.79		275.47	
1	1	3.33	186.68	28.69	239.28	12.49	262.18	5.44	272.16	2.37	276.50	1.03
2	1	3.33	208.61	21.93	248.83	9.55	266.34	4.16	273.97	1.81	277.29	0.79
3	1	3.33	225.39	16.77	256.13	7.30	269.52	3.18	275.35	1.38	277.89	0.60
4	1	3.33	238.21	12.82	261.72	5.58	271.95	2.43	276.41	1.06	278.35	0.46
5	1	3.33	248.01	9.80	265.99	4.27	273.81	1.86	277.22	0.81	278.71	0.35
6	1	3.33	255.51	7.50	269.25	3.26	275.23	1.42	277.84	0.62	278.98	0.27
7	1	3.33	261.24	5.73	271.75	2.50	276.32	1.09	278.31	0.47	279.18	0.21
8	1	3.33	265.62	4.38	273.65	1.91	277.15	0.83	278.68	0.36	279.34	0.16
9	1	3.33	268.97	3.35	275.11	1.46	277.79	0.64	278.95	0.28	279.46	0.12
10	1	3.33	271.53	2.56	276.23	1.12	278.27	0.49	279.16	0.21	279.55	0.09
11	1	3.33	273.49	1.96	277.08	0.85	278.64	0.37	279.33	0.16	279.62	0.07
12	1	3.33	274.99	1.50	277.73	0.65	278.93	0.28	279.45	0.12	279.68	0.05
13	1	3.33	276.13	1.14	278.23	0.50	279.15	0.22	279.54	0.09	279.72	0.04
14	1	3.33	277.01	0.88	278.61	0.38	279.31	0.17	279.62	0.07	279.75	0.03
15	1	3.33	277.68	0.67	278.90	0.29	279.44	0.13	279.67	0.06	279.77	0.02
16	1	3.33	278.19	0.51	279.13	0.22	279.54	0.10	279.71	0.04	279.79	0.02
17	1	3.33	278.58	0.39	279.30	0.17	279.61	0.07	279.75	0.03	279.80	0.01
18	1	3.33	278.88	0.30	279.43	0.13	279.67	0.06	279.77	0.02	279.82	0.01
19	1	3.33	279.11	0.23	279.53	0.10	279.71	0.04	279.79	0.02	279.82	0.01
20	1	3.33	279.28	0.17	279.60	0.08	279.74	0.03	279.80	0.01	279.83	0.01

Table 9. Marginal crop and marginal fertilizer values and their TL values

N kg da^{-1}	Marginal ntirogen amount		Marginal nitrogen value TL	b_1 = 4 kg da^{-1} very low		b_1 = 8 kg da^{-1} low		b_1 = 12 kg da^{-1} medium		b_1 = 16 kg da^{-1} adequate		b_1 = 20 kg da^{-1} high	
	N	AN %33		Marginal crop kg da^{-1}	Marginal crop Value TL	Marginal crop kg da^{-1}	Marginal crop Value TL	Marginal crop kg da^{-1}	Marginal crop Value TL	Marginal crop kg da^{-1}	Marginal crop Value TL	Marginal crop kg da^{-1}	Marginal crop Value TL
1	1	3.33	2.55	28.69	48.77	12.49	21.24	5.44	9.25	2.37	4.03	1.03	1.75
2	1	3.33	2.55	21.93	37.29	9.55	16.24	4.16	7.07	1.81	3.08	0.79	1.34
3	1	3.33	2.55	16.77	28.51	7.30	12.41	3.18	5.41	1.38	2.35	0.60	1.02
4	1	3.33	2.55	12.82	21.80	5.58	9.49	2.43	4.13	1.06	1.80	0.46	0.78
5	1	3.33	2.55	9.80	16.67	4.27	7.26	1.86	3.16	0.81	1.38	0.35	0.60
6	1	3.33	2.55	7.50	12.74	3.26	5.55	1.42	2.42	0.62	1.05	0.27	0.46
7	1	3.33	2.55	5.73	9.74	2.50	4.24	1.09	1.85	0.47	0.80	0.21	0.35
8	1	3.33	2.55	4.38	7.45	1.91	3.24	0.83	1.41	0.36	0.62	0.16	0.27
9	1	3.33	2.55	3.35	5.70	1.46	2.48	0.64	1.08	0.28	0.47	0.12	0.20
10	1	3.33	2.55	2.56	4.35	1.12	1.90	0.49	0.83	0.21	0.36	0.09	0.16
11	1	3.33	2.55	1.96	3.33	0.85	1.45	0.37	0.63	0.16	0.27	0.07	0.12
12	1	3.33	2.55	1.50	2.55	0.65	1.11	0.28	0.48	0.12	0.21	0.05	0.09
13	1	3.33	2.55	1.14	1.95	0.50	0.85	0.22	0.37	0.09	0.16	0.04	0.07
14	1	3.33	2.55	0.88	1.49	0.38	0.65	0.17	0.28	0.07	0.12	0.03	0.05
15	1	3.33	2.55	0.67	1.14	0.29	0.50	0.13	0.22	0.06	0.09	0.02	0.04
16	1	3.33	2.55	0.51	0.87	0.22	0.38	0.10	0.16	0.04	0.07	0.02	0.03
17	1	3.33	2.55	0.39	0.67	0.17	0.29	0.07	0.13	0.03	0.05	0.01	0.02
18	1	3.33	2.55	0.30	0.51	0.13	0.22	0.06	0.10	0.02	0.04	0.01	0.02
19	1	3.33	2.55	0.23	0.39	0.10	0.17	0.04	0.07	0.02	0.03	0.01	0.01
20	1	3.33	2.55	0.17	0.30	0.08	0.13	0.03	0.06	0.01	0.02	0.01	0.01

Conclusion

In this study, sunflower-nitrogen calibration was made based on the mineral nitrogen forms (NH_4^+-NO_3^- N) at 0-30 cm soil depth as an alternative to the amount of soil organic matter used in nitrogen fertilization recommendations of sunflower under rainfed conditions. In order to determine the nitrogen fertilizer requirement of sunflower under rainfed conditions, log (279.9-y) = log279.9-0.090b_1-0.117x Mitscherlich calibration equation was determined. These calibration equations were evaluated with current crop and fertilizer prices to determine the amount of fertilizer that should be applied economically to obtain optimum yield in the presence of a certain amount of $NH_4^+NO_3^-N$ in the soil. The results of this study seem to be compatible with the evaluations stated by Mortvedt et al., (1996) regarding the amount of nitrogen that should be applied to sunflower based on the amount of mineral nitrogen in the soil.

Antoniadis et al., (2013) found no significant relationship between nitrate nitrogen and other soil properties (organic matter, texture, pH) when one-by-one correlations were sought in the model they developed to determine the nitrogen fertilizer requirements of sunflower, wheat, and maize, however, a significant relationship was found when multiple regression was performed when all soil properties were treated as independent variables. According to the results of this study, the level of mineral nitrogen in the soil can be used to determine the amount of nitrogen to be applied to plants such as sunflower, maize, and wheat.

Within the scope of the study, calibration equations could be obtained based on the amount of $NH_4^+NO_3^-N$ at 0-30 cm depth. Therefore, it is recommended to use the log (279.9-y) =log279.9-0.090b_1-0.117x functional equation to determine the nitrogen fertilizer requirement of sunflower under rainfed conditions in the Thrace Region. The use of these equations and their effects on yield can be determined by future studies.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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Author Contribution

MAG: Conceptualization, Data Curation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Project Administration, Resources, Supervision, Visualization, Writing -original draft. **TAK:** Data Curation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Resources, Visualization, Writing -review and editing.

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