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Sulphur Pollution and its Dependency on the Altitude in the West Anatolian Scots Pine Forest

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Abstract
In this study, the pollution levels of sulphur and its impact, depending on altitude were examined in the West Anatolian (Turkmen Mountain) Scots pine (*Pinus sylvestris* subsp. *hamata*) forests. According to the average values, it was found that the total sulphur amount was 1243-1658 ppm, 1526-2003 ppm, 1387-1809 ppm in one-year old, two-year old and three-year old needles respectively. It was detected that there was a significant and negative relationship between altitude and the total sulphur amount in the needles ($P<0.05$). The sulphur amount in the forest floor decreased with altitude but this decrease was not significant ($P>0.05$). Sulphur in the B, C and Cv horizons of the soil correlated with the altitude positively ($P<0.05$), but no significant correlation was found between altitude and the sulphur amount of Ah, Ael and Bst horizons ($P>0.05$). According to the results, The Turkmen Mountain Scots Pine Forest is under a sulphur pollution threat and the pollution has intensified more at the bottom of the mountain.
Keywords: Pollution, scots pine, sulphur, Türkmen Mountain, West Anatolia.

Batı Anadolu (Türkmen Dağı) Sarıçam Ormanlarında Kükürt Kirlilik Düzeyleri ve Bunun Yükseltiye Bağlı Olarak Değişimi

Özet
Bu çalışmada Batı Anadolu (Türkmen Dağı) sarıçam (*Pinus sylvestris* subsp. *hamata*) ormanlarında kükürt kirlilik düzeyleri ve bunun yükseltiye bağlı olarak değişimi incelenmiştir. Ortalama değerlere göre toplam kükürt miktarı, bir yaşındaki ibrelerde 1248-1658 ppm, iki yaşındaki ibrelerde 1526-2003 ppm, üç yaşındaki ibrelerde ise 1387-1809 ppm arasında bulunmuştur. Yükselti ile ibrelerdeki toplam kükürt miktarı arasında, istatistiksel bakımdan anlamlı ve negatif yönde ilişkiler belirlenmiştir ($P<0,05$). Ölü örtü tabakalarındaki toplam kükürt miktarı genel olarak yükseltiye bağlı azalış göstermektedir ancak bu azalış istatistiksel bakımdan anlamlı değildir ($P>0,05$). Yükselti ile toprak horizonlarındaki kükürt miktarı arasında, BC ve Cv horizonlarında istatistiksel bakımdan anlamlı ve pozitif yönde bir ilişki bulunurken ($P<0,05$) Ah, Ael ve Bst horizonlarında anlamlı bir ilişki bulunamamıştır ($P>0,05$). Bu sonuçlara göre, Türkmen Dağı sarıçam ormanları kükürt kirliliği tehdidi altında olup, kirlilik daha çok alt yamaçlarda yoğunlaşmaktadır.
Anahtar Kelimeler: Batı Anadolu, kirlilik, kükürt, sarıçam, Türkmen Dağı.

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INTRODUCTION

Fast urbanization, industrialization, and widespread use of fossil fuels have resulted in the increase of sulphur in the atmosphere. It is known that sulphur, which is a gas polluting the atmosphere, harms the forest ecosystems directly and/or indirectly (Hrdlicka and Kula 2009). At this point, it is important to take the necessary precautions after determining the pollution levels through various ways. Sulphur dioxide is known as a major pollutant in industrial areas, primarily as causative agents of acid rain (Huseyinova at al. 2009).

In Europe and Asia, the Scots Pine is distributed between 37°-70° North latitude and 7°-137° east longitude; in Turkey between 41° 48' north and 38° 34' south latitude, and also between 43° 05' east and 28° 50' west longitude. In this broad distribution area, it branches 5 subspecies in terms of systematic: subsp. *sylvestris*, subsp. *hamata*, subsp. *lapponica*, subsp. *siberica* and subsp. *kulundensis*. Among these subspecies, *Pinus sylvestris* subsp. *hamata* is distributed in the Crimean, the Caucasus, and Turkey (Richardson 1998). While the total forest area in Turkey is 21,188,747 ha, which covers 27.2% of the country's land, the Scots Pine covers 5.8% of the common forest area with a 1.239.578 ha distribution.

Flowering plants are frequently used for biomonitoring of trace elements (McEnroe and

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Helmisaari 2001, Rossini and Mingorance 2006, Dogan et al. 2007, Kuang et al. 2007, Ozturk et al. 2008, Baslar et al. 2009, Dogan et al. 2010), and S poullition (Yuan-wen et al 2006, Reimann et al. 2007). They show a clear division in the roots, shoots, and leaves, are much larger, and show no difficulty in the separation of the different organs and even tissues (Ozturk et al. 2008). The effects of SO_2 and heavy metals persisting for many years, have inflicted significant damage to the trees. Although air pollution caused by SO_2 mainly creates a threat to vegetation, pollution with heavy metals, is more dangerous to animals and humans (Yilmaz and Zengin 2004). Sulphur and heavy metal deposition has also been found to affect the nutrient status of conifer needles (Huttunen et al. 1985, Zechmeister 1995).

There are some studies on the sulphur pollution of different areas (Karaoz 2001, Kantarci et al. 2005, Sevgi et al. 2001, Yilmaz and Zengin 2004, Reimann et al. 2007). However, there is no studies on the sulphur pollution of the Scots Pine forests in West Anatolia (Turkmen Mountain).

The Turkmen Mountain lies between 39° 16'-39° 38' north latitude and 30° 06'-30° 36' east longitude in the direction of northwest-southeast. Its climax is Turkmen Tepe which is 1826 m (Fig. 1). The northern side of the Turkmen Mountain mainly rocks of dacite and dacitic tuff, and the southern side is riolit and riodacite. In the research area the annual average temperature is between 6.5-9.0°C and rain fall is between 605.7-805.7 mm. At almost all the altitudes on the northern side there is a medium scale water need, however, at altitude of 1250 m the water inadequacy covers a 4 month period from July-October, and at 1350-1550 m the water inadequacy covers a 3 month period from July-September and at 1650 m the inadequacy covers a 2 month period from August-September. The water inadequacy is observed in almost all altitudes of the southern side in the summers of a medium degree and the inadequacy covers the a month period from July-September.

Analysis of foliar elements is a commonly used method for studying tree nutrition and for monitoring the impacts of air pollutants on forest ecosystems (Rautio and Huttunen 2003). When the general distribution of Scots Pine in the world is taken into consideration, Turkmen Mountain is one of the extreme points that the Scots Pine goes is found this for south and is surrounded by tree

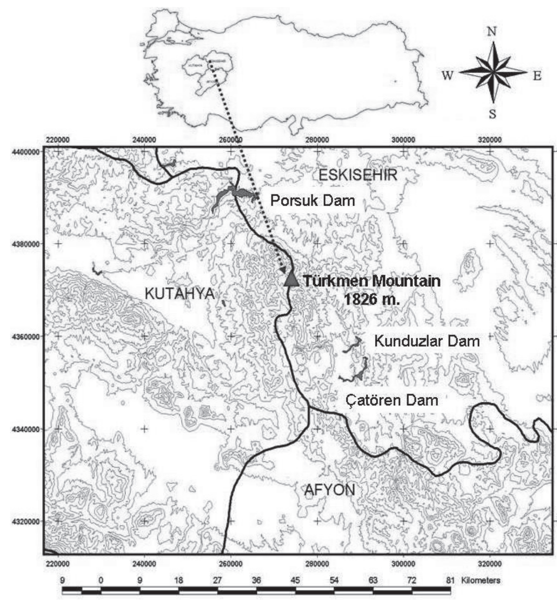

Fig 1. Image of Turkmen Mountain massif.

developing cities (Eskisehir, Kutahya, and Afyon) (Fig. 1). That's why this area is suitable for observing sulphur pollution. Moreover, Turkmen Mountain has the importance of beibg the source of the fresh water and drinkable water needs of the nearby cities of Eskisehir, Kutahya.

In this study, the aim was to determine the pollution levels of sulphur and its impact depending on the altitude in the Scots Pine forests of West Anatolia.

MATERIAL AND METHODS

In this study, the Scots Pine forests of the Turkmen Mountain were chosen as the investigation area and Scots Pine was chosen as the investigation material to determine the pollution levels of sulphur and its changes depending on altitude.

For this stuy of this fixed aim, 48 sample areas were selected. Samples of needle, litter and soil were collected in devaluated from these areas evaluated after being collected. The sample areas were selected, using the following penameters adusidance of roadsides, extremely worn areas, unnatural holes or mounds, steppe and rocky slopes, places that have been exposed to intensive human interference and nearby areas, and the copse areas where the structurally same Scots Pine is generally present. Sample areas were a circular shape and large enough to include at least 15 trees (200-400 m^2). As the Turkmen Mountain is a mound mass lying in the direction of northwest-southeast, illustrations were made from the North and South aspects. The Scots Pine is distributed between the altitudes of 1200-1700 m in the northern aspect and 1400-1700 m in the southern aspect. For this reason, the distribution area of the Scots Pine is divided into 5 altitude ranks in northern aspect (N-NE-NW-E) (1st 1200-1300 m; 2nd , 1300-1400 m; 3rd , 1400-1500 m; 4th, 1500-1600 m and 5th, 1600-1700 m), 3 altitude ranks in the southern aspect (S-SW-SE-W) (6th, 1600-1700 m; 7th, 1500-1600 m and 8th, 1400-1500 m). After that, 48 samplings in total, 5-7 pieces from each altitude rank, were executed (Table 1).

In each sample area one soil profile was opened and then litter samples from leaf, decay and humus layers in a 1 m^2 area of the upper corner of this profile were taken separately. Additionally, the horizons of soil mineral and genetic soil types were determined in the opened soil profile. Later, soil samples of 1 L in volume were collected, using volume cylinders, from the soil horizons that were classified.

The needle samples were collected retrogressively from the terminal sprout of one, two and three-year old needles in the 3. branch conjunction in the first week of October during the period of late September, and initial march.

Soil samples taken using volume cylinders were sieved though a 2 mm sieve and the weight of the refined soil was found by during at 105°C, the reactions of soil samples were determined by the process of watering them with the ½, 5 (pH) distilled water and a night rest, and were calculated with pH meter with glass electrode. The sulphur of the soil was determined according to the turbid metric system and the calculations were carried out using a Spectronic 20D colorimeter device.

The dead cover samples from leaves, decays and humus were dried in a incubator for 48 hours at 65°C, and then weighted and prepared for analysis after being ground. The needle samples were dreid in an incubator for 48 h 65°C, than ground for analysis.

The sulphur in the needle and dead cover samples was determined by the turbidimetric barium sulphate method using the Spectronic 20D colorimeter device (Chapman and Pratt 1982). The correlation of the altitude of the variables of soil, dead cover, and needles was determined by correlation analysis. Using SPSS 10.0 for Windows.

RESULTS

The data related to the soil, forest floor and needles are given as follows respectively.

Soil Characteristics

The soil in the research area is grey brown forest soil type and all the Ah, Ael, Bst, BC and Cv horizons are available in all soil profiles of the sample areas. The actual acidic average values according to the horizons of soils in the altitude levels was found as 5.52-6.13 in the Ah horizon, 5.62-6.16 in the Ael horizon, 5.74-6.14 in the Bst, 5.76-6.41 in the BC, and 5.70-6.49 in the Cv horizons. According to data, the actual acidity of the the soils is mid-slight acidity. A negative relationship was detected between the altitude and the actual acidity of soil horizons, namely, $P<0.01$ in the Ah horizon, $P<0.05$ in the the Bc horizon. There is no significant relationship between altitude and statistics in the Ael, Bst and the Cv horizons. The pH of soil horizons decreases parallel to the increase in altitude. The explanation of this situation can be the fact that there is a rise in the rain with the higher altitude and the washing of the soil with rain.

The sulphur amount decreased regularly from the Ah horizon to the Cv horizon along the soil cross section. The sulphur amounts of the soils in the altitude levels was determined according to the average values, of 11-26 ppm in Ah, 7-13 ppm in Ael, 4-8 ppm in Bst, 2-6 ppm in BC and 2-6 ppm in the Cv horizons (Fig. 2).

While there is a positive relationship in the Bc horizon at a significance level of $P<0.01$ and in the Cv horizon at the significance level of $P<0.05$, there is no meaningful relationship in Ah, Ael and Bst in terms of statistics (Table 2).

The sulphur amount in 1 m^3 of soil according to the average figures was found as 2.0 gm^{-3} in the first altitude rank, 1.9 gm^{-3} in the second altitude rank, 2.8 gm^{-3} in the third altitude rank, 4.0 gm^{-3} in the fourth altitude rank, 3.6 gm^{-3} in the fifth altitude rank and 3.9 gm^{-3} in the sixth altitude rank, 4.9 gm^{-3} in the seventh altitude rank, 4.6 gm^{-3} in the eighth altitude rank. A statistically meaningful relationship was defined at the significance level of $P<0.01$ between the sulphur amount in 1 m^3 of soil volume and altitude.

The average refined soil amount in 1 m^3 at the altitude ranks was 454.7 kgm^{-3} in the first altitude rank, 636.5 kgm^{-3} in the second altitude rank, 668.0 kgm^{-3} in the third altitude rank, 707.3 kgm^{-3} in the fourth altitude rank, 671.7 kgm^{-3} in the fifth altitude rank, 649.2 kgm^{-3} in the sixth altitude rank, 691.6 kgm^{-3} in the seventh altitude rank and 681.2 kgm^{-3}

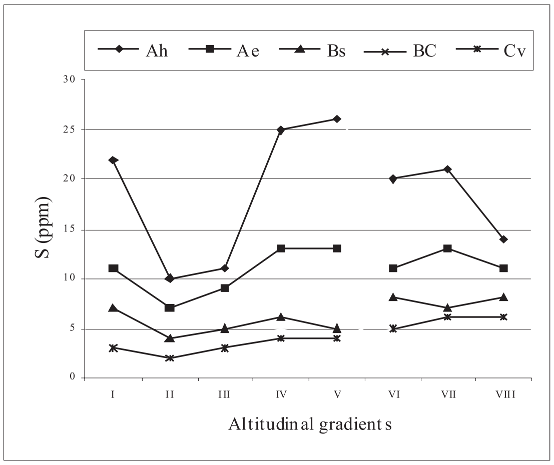

Fig 2. Changes in the sulphur amount of the soil horizons with altitude.

Table 1. Sampling plots on altitudinal gradients.

Altitudinal gradients	Elevation (m)	Slope	Number of sampling plot	Number of soil sample	Number of forest floor sample	Number of needle sample
I	1200-1300	North	6	6x5=30	6x3=18	6x3=18
II	1300-1400	North	6	6x5=30	6x3=18	6x3=18
III	1400-1500	North	6	6x5=30	6x3=18	6x3=18
IV	1500-1600	North	7	7x5=35	7x3=21	7x3=21
V	1600-1700	North	6	6x5=30	6x3=18	6x3=18
VI	1600-1700	South	6	6x5=30	6x3=18	6x3=18
VII	1500-1600	South	6	6x5=30	6x3=18	6x3=18
VIII	1400-1500	South	5	5x5=25	5x3=15	5x3=15
Total			48	240	144	144

Table 2. Relationships between the altitude and the sulphur amount in the soil.

Variables	Soil horizons					Values of soil in $1m^3$ volume
	Ah	Ael	Bst	BC	Cv	
Elevation	0.252^{ns}	0.230^{ns}	0.144^{ns}	0.383^{**}	0.357^{*}	0.538^{**}

(ns: non-significant, *: significant at 0.05 level, **: significant at 0.01 level)

in the eighth altitude rank. There is a positive relationship between altitude and the refined soil in 1 m^3 ($P<0.05$). The refined soil in 1 m^3 volume increases in both aspects until the 1500-1600 m altitude rank and then decreases at the 1600-1700 m altitude ranks.

Characteristics of Forest Floor

The forest floor of the Scots Pine forest the in Turkmen Mountain is of mull type humus. According to average figures the weight of the forest floor was found as 677-1293 gm^{-2} in the leaf layer, 1039-1996 gm^{-2} in the decay layer and 362-625 gm^{-2} in the humus layer. There is no statistical significance between altitude and the weight of the dead cover layer of leaves and humus but there is a significant relationship between the altitude and the rotten layer. The amount of forest floor in unit amount according to average figures was found 2478 gm^{-2} in the 1st altitude rank, 2507 gm^{-2} in the 2nd altitude rank, 2326 gm^{-2} in the 3rd altitude rank, 3081 gm^{-2} in the 4th altitude rank, 3425 gm^{-2} in the 5th altitude rank, 3475 gm^{-2} in the 6th altitude rank, 3414 gm^{-2} in the 7th altitude rank and 2878 gm^{-2} in the 8th altitude rank. A positive relationship at the significance level of $P<0.01$ was found between the forest floor of unit amount and altitude.

While the sulphur amount among in all the altitude ranks is the highest in the humus layer decay and leaf layers follow it. According to the average figures, sulphur amount of the forest layer was found as 1410-1686 ppm in the leaf layer, 1706-1946 ppm in decay layer, 2127-2324 ppm in humus layer. The sulphur amount in the forest floor decreases generally depending on altitude (Fig. 3). However, no statistically meaningful relationship was found between sulphur amount of the forest floor and altitude ($P>0.05$).

According to the average figures, the sulphur amount of the forest floor in a 1 m^3 area was found as 4.71 g m^{-2} in the 1st altitude rank, 4.63 gm^{-2} in the 2nd altitude rank, 4.25 gm^{-2} in the 3rd altitude rank, 5.31 gm^{-2} in the 4th altitude rank, 5.72 gm^{-2} in the 5th altitude rank, 6.39 gm^{-2} in the 6th altitude rank, 5.99 gm^{-2} in the 7th altitude rank, and 5.30 gm^{-2} in the 8th altitude rank. A positive relationship at the significance level of $P<0.05$ was found between the total amount of sulphur in 1 m^2 area of forest floor and altitude (Table 3).

Sulphur Amount in the Needles

The sulphur amount in the needles was the most in the two years old needles in all the altitude ranks and the three year old needle followed. According to the average figures, the sulphur amount was found as 1248-1658 ppm in the one year old needles, 1526-2003 ppm in the two years old needles, and 1387-1809 ppm in three year old needles (Fig. 4).

The negative relationships which were at the significance level of $P<0.05$ in the one year old and three year old needles, and were at the significance level of $P<0.01$ in the two year old needles (Table 4). According to it, the sulphur amount in the one year old, two year old and three year old, needles decreased with altitude increase.

DISCUSSION AND CONCLUSION

In this study, samples of needle, forest floor and soil were examined in order to define the pollution levels of sulphur and its changes depending on altitude in the Scots Pine forests in the West Anatolia

Table 3. Relationships between the altitude and the sulphur amount in the forest floor.

Variables	Forest floor layers			Total per
	Litter	Fermentation	Humus	1 m^2 area
Elevation	-0.207^{ns}	-0.140^{ns}	-0.112^{ns}	0.311*

(ns: non-significant, *: significant at 0.05 level)

Table 4. Relationships between the altitude and the sulphur amount in the needles.

Variables	One year old needle	Two years old needle	Three years old needle
Elevation	-0.335*	-0.435**	-0.322*

(*: significant at 0.05 level, **: significant at 0.01 level)

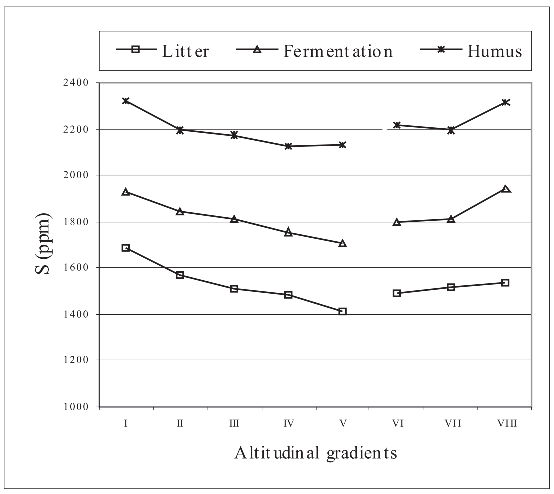

Fig 3. Changes in the sulphur amount of the forest floor layers with altitude.

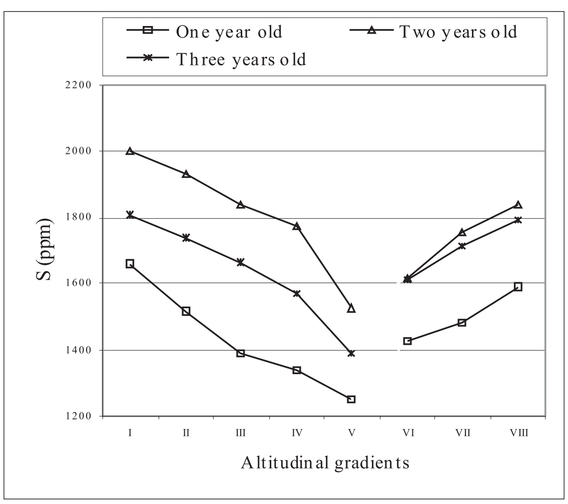

Fig 4. Changes in the sulphur amount of the needles with altitude.

Turkmen Mountains. It is a widespread method to use leaves as a biomonitor for air pollution (SO_2) research (Manninen and Huttunen 2000). However, the amount of nourishment elements in plant organs may be related to the soil and forest floor (Takala at al.1994, Poikolainen 1997), and that's why the needle, forest floor and soil were examined altogether. Air polluters are generally present in atmosphere by forming layers depending on the altitude. Therefore they play more effective roles in the altitude where they are found that's why the samples were collected at different altitudes (1200-1700 m). Additionally, with the consideration of the importance of the direction, the main sample areas for the study were selected from the main aspects of South and North.

Mobile nourishment elements accumulate in the young organs of a plant while nonmobile ones accumulate in the old organs of a plant (Kacar and Katkat 2006). However in this study, the sulphur amount in the needles was established differently depending on age. However, it is reported that sulphur, which is a mobile nourishment element, isn't transported much as it reverses to metabolic compounds easily (Kacar and Katkat 2006). In these studies related to air pollution it was established that sulphur increases depending on the needle age (Kantarci et al. 2005). In this study, although the sulphur amount is higher in older needles, there might be a possibility that there is a probable shift from three year old needles to two year old needles because of the fact that the sulphur amount is higher in the two year old needles than the three year old needles.

The weight of the forest floor was found between 2326-3435 gm^{-2} in the research area while the weight of sulphur was found as 4.25-6.39 gm^{-2}. A finding which was found to be in harmony with the ones related to the Scots Pine (Manninen and Huttunen 2000, Tecimen et al. 2001). A positive relationship was found between the weight and sulphur amount of the forest floor in a 1 m^2 area and altitude. These findings show that the forest floor of the Scots Pine forests in the Turkmen Mountain gets different qualities depending on altitude (Table 5).

In the studies carried out in Turkey with one year old and two year old the Scots Pine needles sulphur content was found between 0.113-0.135% (Sevgi et al. 2001). It is seen that the sulphur amount in one year old and two years old needles is high. Kantarci and Karaoz (1998) reported that the sulphur amount of unwashed needles in fresh air is between 1000-1100 ppm. It was reported that in the studies related to air pollution in Turkey the sulphur amount of

Scots Pine needles is 1100-2049 ppm in the one year old needles, 1510-2308 ppm in the two year old needles, and 1710-2474 ppm in the three year old ppm (Kantarci et al 2005). It was reported that in the study carried out by Karaoz (2001) it was 1310-1850 ppm in one year old needles, 1600-2145 ppm in two years old needles, and 2550 ppm in three year old needles.

Mosses have been collected from transects along altitudinal gradients on the five mountain ranges within the northern and eastern Alps and the results show a remarkable increase of S concentrations with rising altitude (Zechmeister 1995). While the sulphur amount in needles decreases depending on altitude, the sulphur amount in the forest floor and soil increases. It is important to shows that the sulphur amount in needles is not soil or the forest based but originates in the atmosphere. On the other hand, the increase of the sulphur amount in forest floor and soil depending on altitude raises as a question which needs explanation.

The increase of the sulphur amount depending on the altitude might be related to the physical properties of the soil and the forest floor in the research area. The fine soil amount in the soil of 1 m^3 increased at the altitudes of 1500-1600 m in both aspects but decreased at 1600-1700 m. Likewise, the sulphur amount in 1 m^3 of soil increased depending on the altitude. As sulphur and the refined soil amount in 1 m^3 increased similarly to altitude, it shows that the sulphur increase in the soil is because of an increase in the refined soil.

No meaningful relationship between the sulphur amount of the forest floor and altitude was found. However, the sulphur amount of the forest floor in 1 m^2 increases with altitude. The decrease of heat, depending on the altitude, revealed the slowdown of the decomposition of the floor dead cover, an increase in the dead cover floor and an increase in the amount of sulphur.

Needles which are one, two, and three-years old, shows that thesulphur amount decreased parallel with the altitude increase. However, the sulphur amount in 1 m^2 of forest floor and soil, increased depending on altitude. The sulphur increase in the needles shows no relationship with the sulphur in the soil but shows a relationship with the sulphur amount in the air. According to the current data, the Turkmen Mountain Scots Pine forests are under the threat of sulphur pollution where the pollution is already seen in the lower altitudes. The possible reason four this fact might be that the molecule weight of the sulphur is greater thus it is dense in the lower levels of the atmosphere. On the other hand, in the research area, throughout the night times the cool weather and the mountain winds are very often observed and this causes fog towards the lower slopes of the mountain. It is considered that the fog causes the higher amounts of sulphur accumulation in the needles of the trees in the lower altitudes. As a result, the eastern Anatolia (Turkmen Mountain) Scots Pine communities are under the threat of sulphur pollution. It could be said that the trees was under a high risk in our study area. This circumstance arises to the genetic reservation of Scots Pine in the Turkmen Mountain mass which is the at the most southern end when the general spread of the Scots Pine in the world is taken into account. Immediate precautions should be taken against sulphur pollution primarily and all other sources of pollution that threaten the Scots Pine forests in the region.

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