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Changing the Vegetation Properties Depending on the Distance to an Industrial Facility on the Example of Pumice Mining Dust

Sule Erkovan[1], Sedat Severoglu[2], Mehmet Kerim Gullap[2], Halil Erkovan[1*], and Ali Koc[1]

1- Eskisehir Osmangazi, University Faculty of Agriculture, Department of Field Crops, Turkey.

2- Ataturk University, Faculty of Agriculture, Department of Field Crops, Turkey.

***Correspong author; erkovan@ogu.edu.tr,**

ABSTRACT

Mining areas have become a major environmental problem for developing countries due to their undesirable effects of dust pollution and digging operations. The objective of this study was to examine the effect of dust emitted from pumice mining areas on canopy coverage, functional plant groups and seed bank, and growth performance of common plants in areas surrounding mining. Canopy coverage increased with decreasing dust accumulation, while dust led to different effects on functional plant groups and seed bank. The height and the bunch of *Festuca ovina* L., the dominant plant species, increased with distance from the dust center. To minimize the negative effect of dust emission on natural environment, it must be reduced by using appropriate technologies during operation.

Keywords: mine, above-ground vegetation, seed bank, growing properties.

INTRODUCTION

Rangelands are a major source of feed for both domestic and wild herbivores. However, rangelands supply different services beyond this such as wood, edible plants, water, minerals, biodiversity, recreation area, habitat for wildlife, etc. (Holechek *et al*., 2011). While these areas have been degraded mainly by overgrazing, at the present environmental pollutants originating from the byproducts of industrialization and urbanization occur. Mining not only directly affects the operation area's morphological, biological, and physiological structure, but also affects characteristics of the surrounding area by emitting dust (Farmer, 1993; Ulrichs *et al.*, 2008; Yan *et al.*, 2011). Thus, dust causes considerable economic, social, and physical damage around mining areas (Katare *et al*., 2013; Tozer and Leys, 2013).

The pumice industry is important for Erzurum and its surroundings, and deposits lie mainly below rangelands areas in the province. A high amount of dust is emitted around during both the mining and manufacturing processes of pumice production. Although toxic pollutants are not emitted from pumice mining area, emitted dust causes environmental pollution and it damages plant communities by burning or sandblasting depending on particle size and distance from mining and manufacturing areas. Airborne particle size varies between 1 nm and 100 μm (Graedel and Crutzen, 1994), and its dispersion distance varies depending on particle size (Ulrichs *et al.,* 2008; Yan *et al.,* 2011; Turner, 2013). Thus, the effects of dust on the environment change radially.

Research has generally focused on emission of phytotoxic pollutants, whereas there has been limited study on dust pollution originating from mining (Farmer, 1993; Tripathy *et al.,* 2013; Katare *et al.,* 2013). Dust particulates arise from various sources, with deposition near source due to gravity, but particles smaller than 10 μm can be transported by wind for several meters or kilometers depending on size (Turner, 2013; Zia-Khan *et al.,* 2015). The physical and chemical characteristics of particles vary with origin (Tripathy *et al.,* 2013), and their negative or positive effects on plants vary depending on particle size and content (Cattle *et al.,* 2009; Tozer and Leys, 2013; Chaturvedi *et al.*, 2013). In general, the detrimental effect of dust increase as particle size decrease (Turner, 2013), dust particles can decrease stomatal openings (Chaturvedi *et al.*, 2013), reduce photosynthetic rate (Cook *et al.*, 1981; Zia-Khan *et al.*, 2015), and increase leaf temperature and transpiration (Davison and Blakemore, 1976). Deposition ratio, particulate size, chemical composition, plant species, and even the age and growth stage of the plant have been affected either positively or negatively by dust (Tozer and Leys, 2013; Chaturvedi *et al.,* 2013; Gao *et al.*, 2017).

The effects of dust-fall on plants change depending on plant morphology, age, species, leaf anatomy, and deposition amount and content (Tozer and Leys, 2013; Chaturvedi *et al.*, 2013). The plants affected by dust demonstrate reactions such as chlorophyll degradation, necrosis, and reduction in photosynthesis and plant growth (Chaturvedi *et al.,* 2013).Moreover, dust particulates accumulated on plant leaves decrease light , diffusive resistance, and increase water stress (Davison and Blakemore, 1976; Zia-Khan *et al.,* 2015). The light and gas exchange ratios decrease for dust-covered plant leaves. The plant species response to dust-coverage varies depending on leaf surface properties such as geometry, orientation, epidermal and cuticle properties (Zia-Khan *et al.,* 2015). As a consequence of different responses among plants, competitive ability changes, and species composition of natural plant cover may also change (Ulrichs *et al.,* 2008; Rai and Panda, 2014).

Rangeland plant communities are highly sensitive to changing environmental conditions because plant species respond differently (Gibbens *et al.,* 2005; Han *et al.*, 2008). Krippelova (1982) showed that common species around magnesite factory in Czechoslovakia such as

Lolium perenne, *Polygonum aviculare*, *Poa annua* decreased, and *Puccinellia distans*, *Chenopodium glaucum*, and *Agropyron repens* become dominant after the factory was established. According to Farmer (1993), Sree Rangasamy *et al.* (1973) reported that only nine plant species grew near a cement factory, whereas 54 species were recorded in the broader area in southern India. Dust also affects the soil's physical, chemical, and microbial properties, and alters its nutrient content (Tripathy *et al.*, 2013). Where particulate matter is deposited, plant growth and botanical composition, flora, fauna, and vegetation are affected. This situation area also affect seed bank (soil seed content) abundance and composition (Godefroid *et al.*, 2006; Chaideftou *et al.*, 2009). Rangeland seed banks are seriously affected by botanical composition, which is strongly affected by the environmental condition (Bakoglu *et al.*, 2009; Ozaslan Parlak *et al.*, 2011; Erkovan *et al.*, 2013; Koc *et al.*, 2013).

The objective of this study was to determine the changes of the effects of dust pollution depend on distance a pumice mining area on canopy coverage, botanical composition, and soil seed bank density and composition of the high altitude rangelands in the eastern Anatolia region of Turkey.

MATERIALS AND METHODS

Site description

This study was conducted at the pumice mining and processing area, the Pasinler district of Erzurum province in eastern Anatolia Turkey during 2015 and 2016. The elevation is about 1750 m, and the area is characterized by a harsh climate with a long, extremely cold winter, and a cool, short, dry summer. Mean annual temperature is 5.2 °C, total annual precipitation is 428.1 mm, the majority occurring from September to May, and mean relative humidity is 66.4%. During 2015 and 2016, average temperatures were 7.4 and 5.5 °C, total annual precipitation was 506.9 and 441.20 mm, and relative humidity was 61.1 and 66.4%, respectively (Table 1).

The plots, 100 x 100 m size, were established in four lines, where two of them lies southwest and the others lies southeast directions from the dust-emitting centre (Figure 1). Positions of plots were arranged in considering main wind direction and the flow speed in May, June, July and August is northwest and southeast, and 2.1, 2.2, 1.8, 2.0 Bofor, respectively which reported by Gecit (2002), and every plot was consist of four replications. Thereafter, four sampling unit were selected for vegetation survey and seed bank examination based on distance from the dust emitting centre. Sampling occurred at four plots in every line considering distance from emitting centre which are far 0-500, 500-1000, 1000-1500 and 1500-2000 m from the mining centre and processing area. Sampling areas had been protected from grazing since mining operations were initiated, which was approximately 10 years prior to the research being initiated.

In order to describe main soil properties, four composite soil samples were taken from at the plots at 0-20 cm depth beginning of the experiment. The analyses were done at laboratory of department of soil science, Faculty of Agriculture, Ataturk University based on the methods described in Soil Survey Laboratory Staff (1992) and results summarized as follow. In soil samples, texture classes were sandy-loam at the distance from emitting centre 0-500 m, 500-1000 m, 1000-1500 m, and sandy clay loam at 1500-2000 m. Soil pH was slightly alkaline at the plot 0-500 and 500-1000 m, neutral at the 1000-1500 m plot, and it was slightly acidic in the 1500-2000 m plot. While soil organic matter content changed between 2.0 and 5.2%, soil aggregate stability change 60.67-88.43% among plots. Electrical conductivity changed between 97.6 and 220.1 mS cm^{-1}. Experimental plots soils were poor for plant-available phosphorus but rich for plant-available potassium.

In order to describe main properties of dust, composite dust samples were collected in iron trays, thereafter, dust content and particulate size, which summarized following text, were analysed using a wavelength dispersive x-ray fluorescence spectrometer WDXRFS of ZSX 1000 of Rigaku firm and laser particle size analyser SALD-3001 at laboratory of department of Physical Science, Faculty of Science, Ataturk University. According to analysis results, average C, O, Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Mn, Fe, Rb, Zr and Pd content of the dust were 2.09, 49.55, 1.02, 0.23, 8.72, 30.40, 0.02, 0.04, 0.05, 5.43, 1.30, 0.13, 0.04, 0.94, 0.01, 0.02 and 0.03 %, respectively. Particulate size in the distance from emitting centre 0-500, 500-1000, 1000-1500 and 1500-2000 m were less than or equal to 10 μm, 2.5-10 μm, less than 2.5 μm and more than or equal 0.1 μm, respectively. The dust accumulation were 0-500, 500-1000, 1000-1500 and 1500-2000 m about 8-10, 5-8, 2-6 and 1-2 g m^{-2}, respectively (Personal Observation Erkovan et al.).

Study area vegetation was shortgrass steppe, and the dominant plant was sheep fescue (*F. ovina*). Other common species were annual grasses (AG) *Bromus japonicus*, *Bromus tectorum*, perennial grasses (PG) *Bromus tomentellus*, *Bromus variegatus*, *Koeleria cristata*, *Phleum montanum*, *Stipa lagascea*, *Thinopyrum intermedium*, perennial legumes (PL) *Astragalus microcephalus*, *Lotus corniculatus*, *Medicago papillosa*, annual other families (AOF) *Alyssum desertorum*, *Alyssum murale*, *Galium aparine*, *Minuartia anatolica*, perennial other families

(POF) *Achillae millefolium, Artemisia spicigera, Euphorbia virgata, Helichrysum arenarium, Hypericum scabrum, Teucrium polium, Thymus parviflorus, Ziziphora capitata.*

Canopy coverage and botanical composition

In each sampling unit, 5 transect line each of one 100 m length were established consisted with main wind direction for vegetation survey, and the transects were sampled at 1 m intervals in every line. Vegetation sampling was conducted in late June or early July in both years when common species were flowering, using a modified wheel-point method (Koc and Cakal, 2004). Canopy coverage was calculated as the ratio of total plants recorded versus the number of sampling point and botanical composition calculated (Gokkus *et al.,* 2011). Species composition was grouped into the categories listed above for statistical analysis.

Soil seed bank density

Ten soil cores (10 cm deep x 6 cm diameter) were collected at 50 m intervals along each transect at every sampling plot during the summer dry (mid-August) in both years. Each sample was stored in a cloth-bag after removal of gravel, litter, and roots. Samples were air-dried and stored in the dark at 4 °C up until the following March. Seed banks were determined using a germination method commonly used for field surveys (Pugnaire and Lazaro, 2000). For germination, soil cores were spread on a plastic tray (25 cm diameter and 6 cm deep) to a depth of approximately 2 cm. Trays were placed in a greenhouse under semi-controlled conditions (temperature 20 ^{0}C dark/30^{0}C light (12-hour cycle)), and watered once or twice daily with tap water to maintain a moist surface moist, for 90 days (Sternberg *et al.*, 2003). Emerging seedlings were counted at as soon as identified and recorded and thereafter removed from the tray during the experimental period.

Plant measurements

Plant height and bunch diameter of dominant species, sheep fescue (*F. ovina*), was recorded in all plots by measuring 20 plants (5 plants in every replication unit) were selected in every plots and measured their height and bunch diameter to the nearest mm.

Statistical analyses

An arc-sin transformation was applied to all plant canopy, botanical composition, and seed bank composition data. All statistical analyses were performed based on the general linear model using the Statview software package (SAS Institute 1998). Means were separated using Bonferroni/Dunn Multiple Range Test.

RESULTS

Canopy coverage and functional plant groups

Mean canopy coverage was significantly ($p<0.0060$) higher in 2015 (57.7%) than 2016 (52.7%) (Table 2). Significant differences ($p<0.0001$) were recorded among the distance from emitting centre for canopy coverage. Canopy coverage increased linearly with distance from the dust emission centre. Increases beyond 1000 m (500-1000 m) did not vary statistically (Table 2). The canopy coverage ratio showed a different trend among the distance from emitting centre. While canopy coverage increased at 0-500 m in the second year compared to the first year, it did not change significantly at 500-1000 m between years and decreased significantly in 1000-1500 and 1500-2000 m in the second year (Figure 2). This different trend caused significantly year x distance interaction.

An overall AG contribution to plant cover was 6.1% and was significantly influenced by year (Table 2), being significantly ($p<0.0005$) higher in the second year. There were no significant changes in AG contribution to plant cover as distance from dust emission centre increased.

There was a strong effect of year, distance, and their interaction on PG ratio ($p<0.0001$) (Table 2). PG ratio was higher in 2015 (33.6%) than in 2016 (18.9%) (Table 2; Figure 2). Also, the PG ratio was highest at 1500-2000 m plots (31.5%) than the others. While the PG ratio did not change significantly at 500-1000 m between years, but was higher at the other distance from emitting centre in the first year.

There was no significant effect for years ($p<0.0537$), but a significant effect for distances ($p<0.0001$) for the PL ratio. Also, the two-way interaction was not significant ($p<0.5748$) for the PL ratio. PL ratio was higher at 1000-1500 and 1500-2000 m than closer plots (Table 2).

The average AOF ratio of the years and the distances showed a significant difference ($p<0.0001$), but two-way interactions were not significant ($p<0.0572$). AOF ratio was higher in the year 2016 than 2015, and it was higher 500-1000 m (22.0%) compared to the other distances from emitting centre (Table 2).

The POF ratio was affected by distance from the centre, declining until 1000-1500 m and thereafter increasing (Table 2).

Soil seed bank density

Total seed density in the seed bank did not change significantly between years but it changed significantly among distance from emitting centre (Table 3). Year by distance interaction for total seed density was insignificant (Table 3 and Figure 3). As the distance from the emission centre increased, seed number per m^2 was increased (Table 3).

Average AG seed number was not affected by year or distance, and there was no significant interaction (Table 3 and Figure 3).

There was a strong effect of years ($p<0.0164$) and distance ($p<0.0440$) on soil seed bank density of PG, but their interaction was not significant ($p<0.6753$). Soil seed bank density of PG was 290.2 seed m^2 in 2015 and 481.4 m^2 in 2016 and it increased regularly away from the emission centre. Soil seed bank densities of PG were 227.3, 261.9, 485.7, and 568.3 m^2 for the distance from emitting centre 0-500, 500-1000, 1000-1500 and 1500-2000 m, respectively (Table 3 and Figure 3).

Legumes content in soil seed banks was lower and unevenly distributed in the experimental area, therefore legumes added forbs groups considering their life span. The effect of the year ($p<0.1918$) and two-way interaction ($p<0.9869$) on AOF was not significant but the distance ($p<0.0001$) effect was significant. It was approximately 569.9 AOF seed per m^2 in the experimental area (Table 3) and it varied (263.5 and 1252.4 seed m^{-2}) greatly among the distance from emitting centre (Table 3 and Figure 3).

An average seed number of POF in the seed bank was 689.0 and it did not change statistically depending on years but increase significantly ($p<0.0001$) in line with increasing distance from dust emitting centre in the area (Table 3). Since POF seed number increases in the seed banks showed a similar trend based on distance from dust emitting centre in both year, years by distance interaction was not significant.

Dominant plant height and bunch size

Dust significantly suppressed plant vitality, the changes in plant height and bunch size of sheep fescue (Table 3). This decreasing trend was similar in both years with respect to both plant height and bunch size (Figure 4).

DISCUSSION

Canopy coverage

Stress factors have different effects on plants depending on their physiological and morphological properties. In general, as the influence of stress factor increase, plant mortality increases (Ulrichs *et al.*, 2008; Katare *et al.*, 2013). As the stress factor influence decrease depending on increasing with distance from the dust-emitting centre plant longevity increase (Wang, 2004; Li *et al.*, 2011; Yan *et al.*, 2011) and consequently, canopy coverage increase as the distance increase. The differences between years may be a consequence of differences in prevailing climatic conditions, with precipitation patterns different between years, particularly the latter months. Higher April precipitation in 2015 must probably have washed leaf surfaces and decreased dust accumulation at the beginning of the growing season. Distance from 0-500 m plots received more dust, and precipitation was perhaps insufficient to remove all dust deposition from leaves, so perhaps leading to a year x distance interaction.

Species groups

The plants are differentially affected by dust deposition (Ulrichs *et al.*, 2008). Thus, functional plant groups exhibited different responses to dust deposition, modified by different years and distance from the centre. The contribution of annual plants into botanical composition was higher in the second year. This situation could be related to the climatic condition because June and July in the second year received more precipitation. This situation support survives of annual plants seedling and consequently, their contribution to botanical composition increased. Similar results were also reported by Hegazy (1996), Singh (2006). Annual grasses frequency was not affected by distance from the emission centre, whereas annual plant species belong to the other families were affected significantly. This situation mainly originated from the distance from emitting centre 500-1000 m plots records because quite higher annual the other family plants were recorded in this plots (Table 2). This situation probably originated decreasing dust effect due to washing of precipitation and lower perennial grasses frequency because perennial grasses that suppress the other plants under favorable condition (Erkovan *et al.* 2011) frequency increased significantly in line with moved away from dust emitting centre after these plots.

In the second experimental years, while PG decrease, forbs (PL and POF) increased. This situation probably originated climatic differences between the years because more precipitation in the second growing season must causes washing dust deposition from leaves of forbs and decreases dust side effect and consequently forbs vigor increase. These results cause an increase of forbs frequency in the botanical composition in the second year because broad and hairless leaves are more suffer dust deposition compared to grasses leaves (Tripathy *et al.*, 2013).

The adverse effects of dust deposition on perennial plants can be more pronounced compared to the annuals (Hegazy, 1996; Singh, 2006). Thus, perennial plants increased in the botanical composition because of decreased dust deposition in line with away from dust emitting centre. Although there were no significant differences in perennial grasses frequency in the second experimental years among the distance from emitting centre except for 0-500 m plots, it was increased linearly in the first year in line with increased distance from dust emitting centre (Figure 2). This situation probably originated from climatic differences between years.

Significant changes in both plant height and bunch size of sheep's fescue were recorded with increasing distance from the dust-emitting centre. As away from the dust emitting centre, both plant height and bunch size increased significantly. These results confirm that dust causes a negative effect on plant vigor decrease as distance increase from dust emitting centre (Table 2). Dust deposition has been recorded to decrease stomatal openings, reduce the photosynthetic rate and increase leaf temperature and transpiration (Joshi and Swami, 2009; Chaturvedi *et al.*, 2012; Rai and Panda, 2014; Zia-Khan *et al.*, 2015).

The total seed number in the seed bank increased with distance from the dust-emitting centre (Table 3). This situation must probably be related to the negative effect of dust deposition on plant vigor because dust deposition, which is a major stress source in the experimental area. The detrimental effect of dust decomposition decreases away from the dust-emitting centre (Hegazy, 1996; Fakhry and Migahid, 2011), and plant vigor increases. These situations cause an increase in seed production (Hegazy, 1996).

Except for annual grasses, seed number of all plant groups in the per unit area increased with increasing distance from the centre, as did total seed number. This situation could be related to the effect of dust deposition on plant vigor because healthy plants produce more seeds (Hegazy, 1996; Fakhry and Migahid, 2011; Koc *et al.*, 2013). Annual grasses grow and complete their life span during the moistly period in the season and this condition decreases the side effect of the dust because rain removes deposited dust (Hegazy, 1996; Fakhry and Migahid, 2011). Therefore, annual grass seed production may be less affected by emitted dust compared to the other plant groups. This explanation may contribute to explain why annual grasses frequency was higher around dust emitting centre. Although years by distance interaction on perennial grasses seed number, the higher perennial seed number at the 1000-1500 and 1500-2000 m plots in the second experimental year caused statistically differences between years with respect to perennial grass seed number (unpresented data). The growing season of this year received more precipitation, this condition may alleviate dust stress and the plants produce more seeds. Because seed bank samples were taken summer dry period of the season.

CONCLUSION

There is strong correlation between wind and dust accumulation, which the efficiency of accumulating dust dramatically declines from emitting centre distance increase. The amount of dust carried by the wind decreases as moves away from the emitting center. Both vegetation and seed banks were negatively affected by emitted dust. These effects were more pronounced as closed to emitting centre. Plant vigority, density and diversity affect negatively as closed to the dust emitting centre. This situation will causes loss biodiversity and decrease in range carrying capacity. Further research on the effect of dust on individual plant species is necessary to determine those plants suitable for restoration of dust-affected areas. Above all, it is urgently need to use of environmental friendly technology in mining areas to save environment and sustainable use of natural resource.

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Table 1. Monthly precipitation, temperature and relative humidity of experimental years (2015 and 2016) and long-term average (1990-2016).

	Total precipitation (mm)			Mean air temperature °C			Mean relative humidity (%)		
	2015	2016	LT	2015	2016	LT	2015	2016	LT
January	26.1	17.8	16.2	-6.0	-9.4	-10.5	76.2	82.7	79.1
February	34.0	25.0	20.1	-4.5	-4.9	-9.1	80.4	84.1	78.8
March	37.9	26.4	33.9	0.2	1.1	-2.3	70.2	70.5	75.1
April	88.6	39.4	57.0	5.3	7.1	5.5	61.6	58.9	67.3
May	81.5	64.8	66.2	10.6	10.5	10.5	63.8	65.9	64.3
June	28.5	88.6	42.6	17.0	14.7	14.9	50.3	63.7	59.0
July	5.8	17.8	23.4	21.2	19.9	19.2	40.3	53.7	52.8
August	38.8	17.4	15.7	21.2	20.9	19.6	42.8	44.0	49.0
September	3.9	76.2	21.4	18.3	12.5	13.9	39.2	57.4	51.8
October	131.3	18.6	49.6	9.4	7.7	7.7	69.7	64.0	65.9
November	15.4	21.8	27.0	2.8	-1.7	-0.2	60.5	71.6	73.6
December	15.1	27.4	22.2	-6.5	-11.4	-7.2	77.7	80.3	79.9
Total/Mean	506.9	441.2	428.1	7.4	5.5	5.2	61.1	66.4	66.4

Table 2. Canopy coverage and functional plant groups' frequency on the experimental area's rangeland plant cover (%).[1]

	Canopy coverage	AG	PG	PL	AOF	POF
Year (Y)						
2015	57.7 A	4.2 B	33.6 A	7.4	11.8 B	49.6
2016	52.7 B	8.0 A	18.9 B	9.6	17.6 A	47.2
Distance (D)						
0-500	31.1 C	6.3	23.0 B	6.9 B	14.5 B	54.5 A
500-1000	53.1 B	4.3	21.4 B	2.5 B	22.0 A	51.5 B
1000-1500	66.5 A	7.1	29.1 A	13.3 A	13.8 B	42.6 C
1500-2000	69.9 A	6.8	31.5 A	11.2 A	8.9 C	45.0 C
Average	55.2	6.1	26.3	8.5	14.7	48.4
Y	**	**	***	ns	***	ns
D	***	ns	***	***	***	***
YxD	***	ns	**	ns	ns	ns

[1]Values followed by capital in a column shows significantly differences at P < 0.05, P < 0.1 and P < 0.01 levels, respectively, using Bonferroni/Dunn multiple range test. ns: No statistical difference at p < 0.05, p < 0.1 and p <

0.01. *: Statistical difference at p < 0.05. **: Statistical difference at p < 0.1, and ***: Statistical difference at p < 0.01.

Table 3. Changes of seed banks and sheep fescue, which is dominate plant, plant height and bunch size depending on years and dust emitting centre in the experimental area.[1]

	Total	AG	PG	AOF	POF	Height	Bunch
Year (Y)							
2015	1388.7	206.7	290.2 B	539.0	690.7	32.3	5.5
2016	1628.6	221.9	481.4 A	600.8	687.2	32.5	5.9
Distance (D)							
0-500	607.0 C	200.3	227.3 B	263.5 B	256.3 B	22.9 C	2.1 C
500-1000	1044.2 B	155.0	261.9 B	444.9 B	456.8 B	31.1 B	2.8 C
1000-1500	1481.8 B	165.3	485.7 A	318.9 B	939.8 A	31.0 B	6.4 B
1500-2000	2901.6 A	336.6	568.3 A	1252.4 A	1103.0 A	44.6 A	11.5 A
Average	1508.6	214.3	385.8	569.9	689.0	32.4	5.7
Y	ns	ns	*	ns	ns	ns	ns
D	***	ns	*	***	***	***	***
YxD	ns	ns	ns	ns	ns	ns	ns

[1]Values followed by capital in a column shows significantly differences at P < 0.05, P < 0.1 and P < 0.01 levels, respectively, using Bonferroni/Dunn multiple range test. ns: No statistical difference at p < 0.05, p < 0.1 and p < 0.01. *: Statistical difference at p < 0.05. **: Statistical difference at p < 0.1, and ***: Statistical difference at p < 0.01.

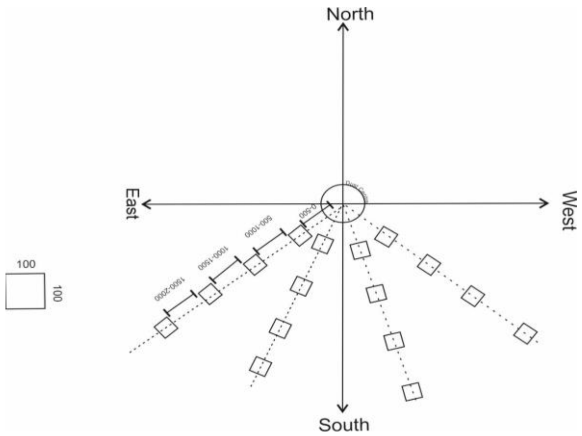
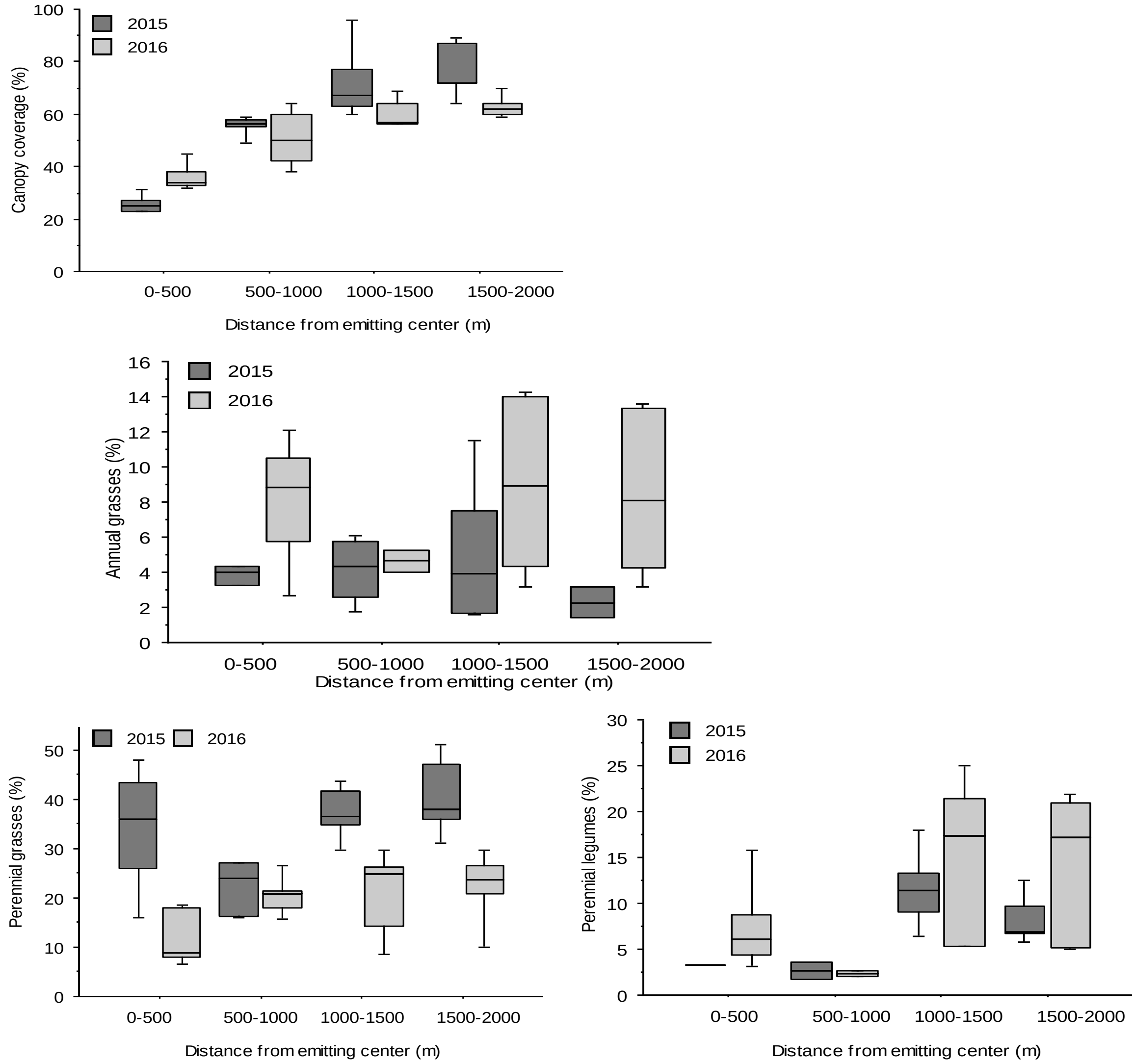


Figure 1. Experimental designs of vegetation survey and seed bank examination based on distance from the dust emitting centre.



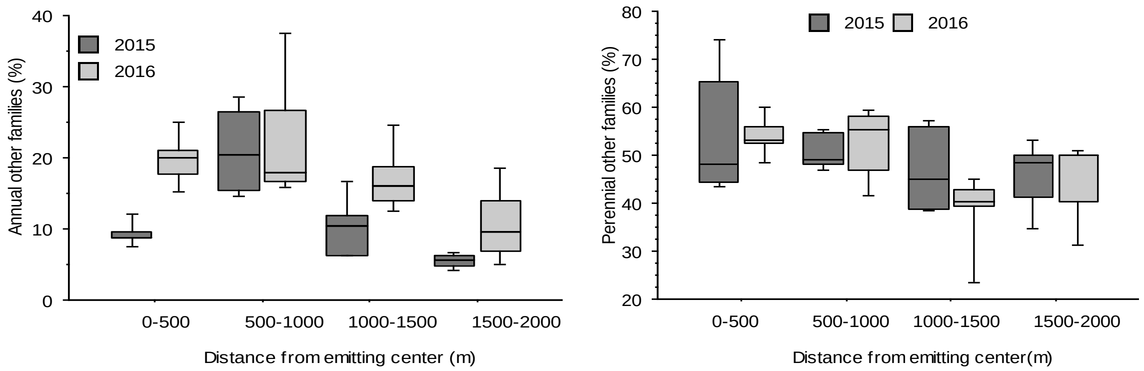


Figure 2. Variation of canopy coverage, functional groups (Annual grasses, Perennial grasses, Perennial legumes, Annual other families and Perennial other families) with aboveground vegetation distance from dust centre.

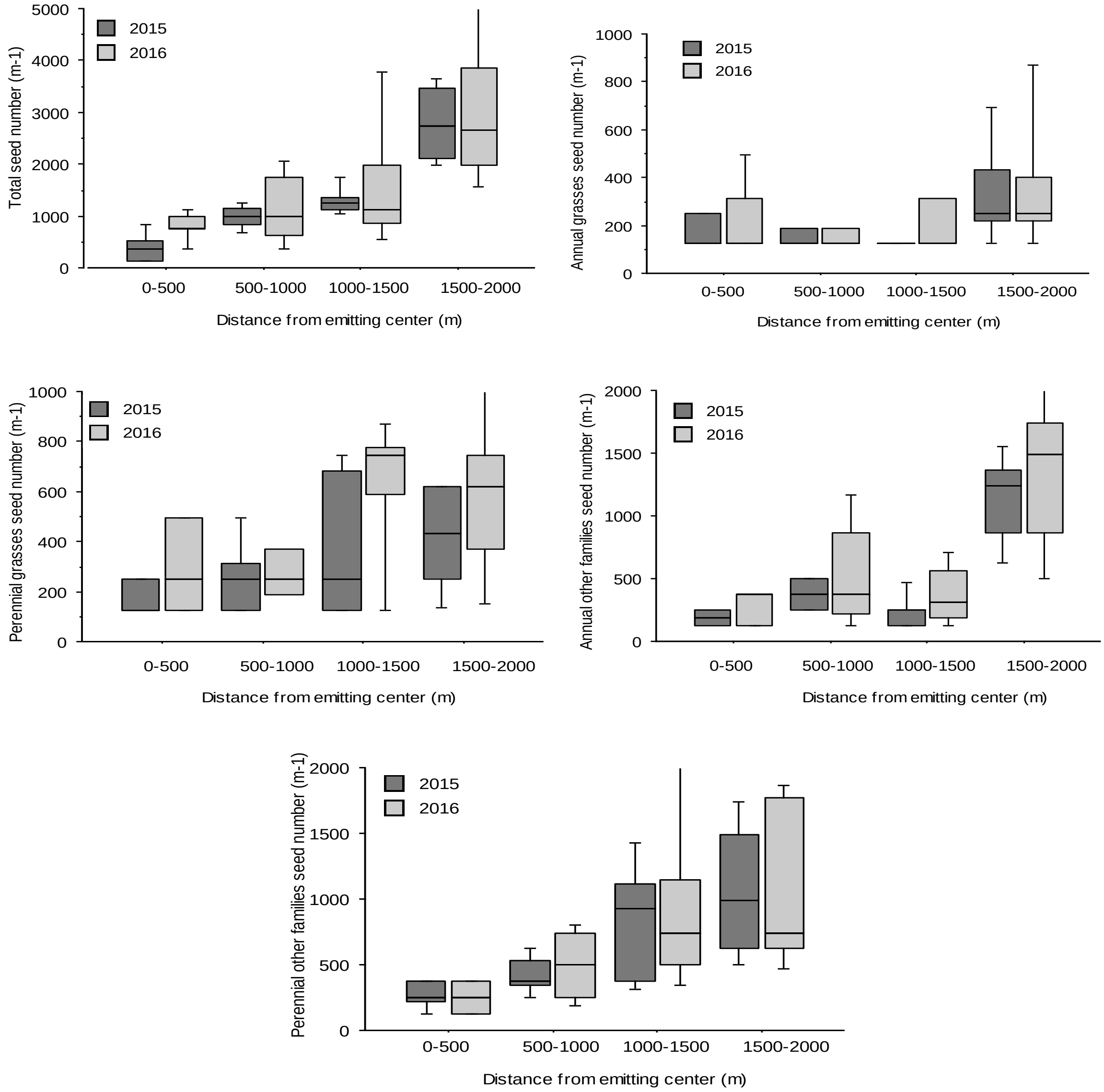


Figure 3. Variation of seed bank with distance from dust centre.

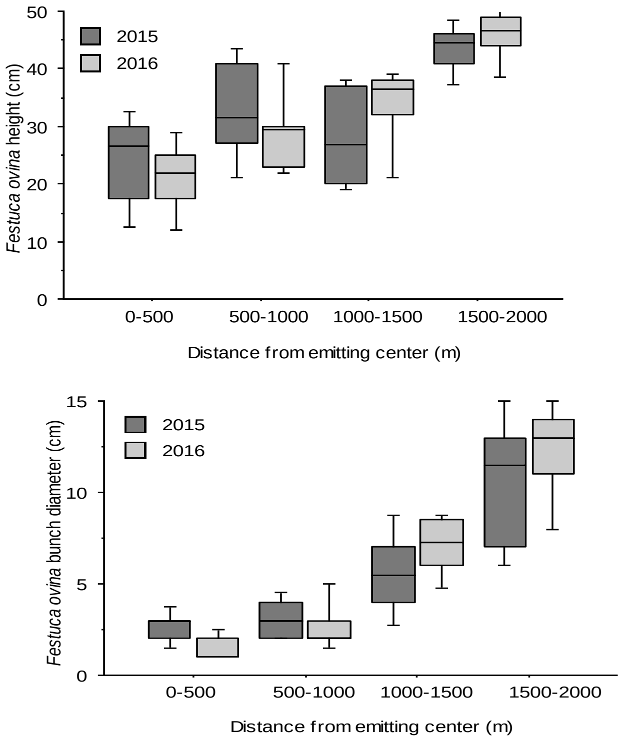


Figure 4. Variation of *F. ovina* height and bunch diameter with distance from dust centre