

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

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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 (Katara *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

38 not emitted from pumice mining area, emitted dust causes environmental pollution and it
39 damages plant communities by burning or sandblasting depending on particle size and distance
40 from mining and manufacturing areas. Airborne particle size varies between 1 nm and 100 μm
41 (Graedel and Crutzen, 1994), and its dispersion distance varies depending on particle size
42 (Ulrichs *et al.*, 2008; Yan *et al.*, 2011; Turner, 2013). Thus, the effects of dust on the
43 environment change radially.

44 Research has generally focused on emission of phytotoxic pollutants, whereas there has
45 been limited study on dust pollution originating from mining (Farmer, 1993; Tripathy *et al.*,
46 2013; Katare *et al.*, 2013). Dust particulates arise from various sources, with deposition near
47 source due to gravity, but particles smaller than 10 μm can be transported by wind for several
48 meters or kilometers depending on size (Turner, 2013; Zia-Khan *et al.*, 2015). The physical
49 and chemical characteristics of particles vary with origin (Tripathy *et al.*, 2013), and their
50 negative or positive effects on plants vary depending on particle size and content (Cattle *et al.*,
51 2009; Tozer and Leys, 2013; Chaturvedi *et al.*, 2013). In general, the detrimental effect of dust
52 increase as particle size decrease (Turner, 2013), dust particles can decrease stomatal openings
53 (Chaturvedi *et al.*, 2013), reduce photosynthetic rate (Cook *et al.*, 1981; Zia-Khan *et al.*, 2015),
54 and increase leaf temperature and transpiration (Davison and Blakemore, 1976). Deposition
55 ratio, particulate size, chemical composition, plant species, and even the age and growth stage
56 of the plant have been affected either positively or negatively by dust (Tozer and Leys, 2013;
57 Chaturvedi *et al.*, 2013; Gao *et al.*, 2017).

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

69 Rangeland plant communities are highly sensitive to changing environmental conditions
70 because plant species respond differently (Gibbens *et al.*, 2005; Han *et al.*, 2008). Krippelova
71 (1982) showed that common species around magnesite factory in Czechoslovakia such as

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

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

87

88 MATERIALS AND METHODS

89 Site description

90 This study was conducted at the pumice mining and processing area, the Pasinler district of
91 Erzurum province in eastern Anatolia Turkey during 2015 and 2016. The elevation is about
92 1750 m, and the area is characterized by a harsh climate with a long, extremely cold winter,
93 and a cool, short, dry summer. Mean annual temperature is 5.2 °C, total annual precipitation is
94 428.1 mm, the majority occurring from September to May, and mean relative humidity is
95 66.4%. During 2015 and 2016, average temperatures were 7.4 and 5.5 °C, total annual
96 precipitation was 506.9 and 441.20 mm, and relative humidity was 61.1 and 66.4%,
97 respectively (Table 1).

98 The plots, 100 x 100 m size, were established in four lines, where two of them lies southwest
99 and the others lies southeast directions from the dust-emitting centre (Figure 1). Positions of
100 plots were arranged in considering main wind direction and the flow speed in May, June, July
101 and August is northwest and southeast, and 2.1, 2.2, 1.8, 2.0 Bofor, respectively which reported
102 by Gecit (2002), and every plot was consist of four replications. Thereafter, four sampling unit
103 were selected for vegetation survey and seed bank examination based on distance from the dust
104 emitting centre. Sampling occurred at four plots in every line considering distance from
105 emitting centre which are far 0-500, 500-1000, 1000-1500 and 1500-2000 m from the mining

106 centre and processing area. Sampling areas had been protected from grazing since mining
107 operations were initiated, which was approximately 10 years prior to the research being
108 initiated.

109 In order to describe main soil properties, four composite soil samples were taken from at the
110 plots at 0-20 cm depth beginning of the experiment. The analyses were done at laboratory of
111 department of soil science, Faculty of Agriculture, Ataturk University based on the methods
112 described in Soil Survey Laboratory Staff (1992) and results summarized as follow. In soil
113 samples, texture classes were sandy-loam at the distance from emitting centre 0-500 m, 500-
114 1000 m, 1000-1500 m, and sandy clay loam at 1500-2000 m. Soil pH was slightly alkaline at
115 the plot 0-500 and 500-1000 m, neutral at the 1000-1500 m plot, and it was slightly acidic in
116 the 1500-2000 m plot. While soil organic matter content changed between 2.0 and 5.2%, soil
117 aggregate stability change 60.67-88.43% among plots. Electrical conductivity changed
118 between 97.6 and 220.1 mS cm^{-1} . Experimental plots soils were poor for plant-available
119 phosphorus but rich for plant-available potassium.

120 In order to describe main properties of dust, composite dust samples were collected in iron
121 trays, thereafter, dust content and particulate size, which summarized following text, were
122 analysed using a wavelength dispersive x-ray fluorescence spectrometer WDXRFS of ZSX
123 1000 of Rigaku firm and laser particle size analyser SALD-3001 at laboratory of department
124 of Physical Science, Faculty of Science, Ataturk University. According to analysis results,
125 average C, O, Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Mn, Fe, Rb, Zr and Pd content of the dust
126 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,
127 0.02 and 0.03 %, respectively. Particulate size in the distance from emitting centre 0-500, 500-
128 1000, 1000-1500 and 1500-2000 m were less than or equal to 10 μm , 2.5-10 μm , less than 2.5
129 μm and more than or equal 0.1 μm , respectively. The dust accumulation were 0-500, 500-1000,
130 1000-1500 and 1500-2000 m about 8-10, 5-8, 2-6 and 1-2 g m^{-2} , respectively (Personal
131 Observation Erkovan et al.).

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

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

140

141 **Canopy coverage and botanical composition**

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

149

150 **Soil seed bank density**

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

162

163 **Plant measurements**

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

167

168 **Statistical analyses**

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

173

174 **RESULTS**

175 **Canopy coverage and functional plant groups**

176 Mean canopy coverage was significantly ($p < 0.0060$) higher in 2015 (57.7%) than 2016
177 (52.7%) (Table 2). Significant differences ($p < 0.0001$) were recorded among the distance from
178 emitting centre for canopy coverage. Canopy coverage increased linearly with distance from
179 the dust emission centre. Increases beyond 1000 m (500-1000 m) did not vary statistically
180 (Table 2). The canopy coverage ratio showed a different trend among the distance from
181 emitting centre. While canopy coverage increased at 0-500 m in the second year compared to
182 the first year, it did not change significantly at 500-1000 m between years and decreased
183 significantly in 1000-1500 and 1500-2000 m in the second year (Figure 2). This different trend
184 caused significantly year x distance interaction.

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

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

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

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

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

203

204 **Soil seed bank density**

205 Total seed density in the seed bank did not change significantly between years but it changed
206 significantly among distance from emitting centre (Table 3). Year by distance interaction for

207 total seed density was insignificant (Table 3 and Figure 3). As the distance from the emission
208 centre increased, seed number per m² was increased (Table 3).

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

211 There was a strong effect of years ($p < 0.0164$) and distance ($p < 0.0440$) on soil seed bank
212 density of PG, but their interaction was not significant ($p < 0.6753$). Soil seed bank density of
213 PG was 290.2 seed m² in 2015 and 481.4 m² in 2016 and it increased regularly away from the
214 emission centre. Soil seed bank densities of PG were 227.3, 261.9, 485.7, and 568.3 m² for the
215 distance from emitting centre 0-500, 500-1000, 1000-1500 and 1500-2000 m, respectively
216 (Table 3 and Figure 3).

217 Legumes content in soil seed banks was lower and unevenly distributed in the experimental
218 area, therefore legumes added forbs groups considering their life span. The effect of the year
219 ($p < 0.1918$) and two-way interaction ($p < 0.9869$) on AOF was not significant but the distance
220 ($p < 0.0001$) effect was significant. It was approximately 569.9 AOF seed per m² in the
221 experimental area (Table 3) and it varied (263.5 and 1252.4 seed m⁻²) greatly among the
222 distance from emitting centre (Table 3 and Figure 3).

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

228

229 **Dominant plant height and bunch size**

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

233

234 **DISCUSSION**

235 **Canopy coverage**

236 Stress factors have different effects on plants depending on their physiological and
237 morphological properties. In general, as the influence of stress factor increase, plant mortality
238 increases (Ulrichs *et al.*, 2008; Katare *et al.*, 2013). As the stress factor influence decrease
239 depending on increasing with distance from the dust-emitting centre plant longevity increase
240 (Wang, 2004; Li *et al.*, 2011; Yan *et al.*, 2011) and consequently, canopy coverage increase as

241 the distance increase. The differences between years may be a consequence of differences in
242 prevailing climatic conditions, with precipitation patterns different between years, particularly
243 the latter months. Higher April precipitation in 2015 must probably have washed leaf surfaces
244 and decreased dust accumulation at the beginning of the growing season. Distance from 0-500
245 m plots received more dust, and precipitation was perhaps insufficient to remove all dust
246 deposition from leaves, so perhaps leading to a year x distance interaction.

247

248 **Species groups**

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

264 In the second experimental years, while PG decrease, forbs (PL and POF) increased. This
265 situation probably originated climatic differences between the years because more precipitation
266 in the second growing season must causes washing dust deposition from leaves of forbs and
267 decreases dust side effect and consequently forbs vigor increase. These results cause an
268 increase of forbs frequency in the botanical composition in the second year because broad and
269 hairless leaves are more suffer dust deposition compared to grasses leaves (Tripathy *et al.*,
270 2013).

271 The adverse effects of dust deposition on perennial plants can be more pronounced
272 compared to the annuals (Hegazy, 1996; Singh, 2006). Thus, perennial plants increased in the
273 botanical composition because of decreased dust deposition in line with away from dust
274 emitting centre. Although there were no significant differences in perennial grasses frequency

275 in the second experimental years among the distance from emitting centre except for 0-500 m
276 plots, it was increased linearly in the first year in line with increased distance from dust emitting
277 centre (Figure 2). This situation probably originated from climatic differences between years.

278 Significant changes in both plant height and bunch size of sheep's fescue were recorded
279 with increasing distance from the dust-emitting centre. As away from the dust emitting centre,
280 both plant height and bunch size increased significantly. These results confirm that dust causes
281 a negative effect on plant vigor decrease as distance increase from dust emitting centre (Table
282 2). Dust deposition has been recorded to decrease stomatal openings, reduce the photosynthetic
283 rate and increase leaf temperature and transpiration (Joshi and Swami, 2009; Chaturvedi *et al.*,
284 2012; Rai and Panda, 2014; Zia-Khan *et al.*, 2015).

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

291 Except for annual grasses, seed number of all plant groups in the per unit area increased
292 with increasing distance from the centre, as did total seed number. This situation could be
293 related to the effect of dust deposition on plant vigor because healthy plants produce more
294 seeds (Hegazy, 1996; Fakhry and Migahid, 2011; Koc *et al.*, 2013). Annual grasses grow and
295 complete their life span during the moistly period in the season and this condition decreases
296 the side effect of the dust because rain removes deposited dust (Hegazy, 1996; Fakhry and
297 Migahid, 2011). Therefore, annual grass seed production may be less affected by emitted dust
298 compared to the other plant groups. This explanation may contribute to explain why annual
299 grasses frequency was higher around dust emitting centre. Although years by distance
300 interaction on perennial grasses seed number, the higher perennial seed number at the 1000-
301 1500 and 1500-2000 m plots in the second experimental year caused statistically differences
302 between years with respect to perennial grass seed number (unpresented data). The growing
303 season of this year received more precipitation, this condition may alleviate dust stress and the
304 plants produce more seeds. Because seed bank samples were taken summer dry period of the
305 season.

306 307 **CONCLUSION**

308 **There is strong correlation between wind and dust accumulation, which the efficiency of**

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

318

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424 **Table 1.** Monthly precipitation, temperature and relative humidity of experimental years (2015
 425 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

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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

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

431 0.01. *: Statistical difference at $p < 0.05$. **: Statistical difference at $p < 0.1$, and ***: Statistical difference at $p <$
 432 0.01.

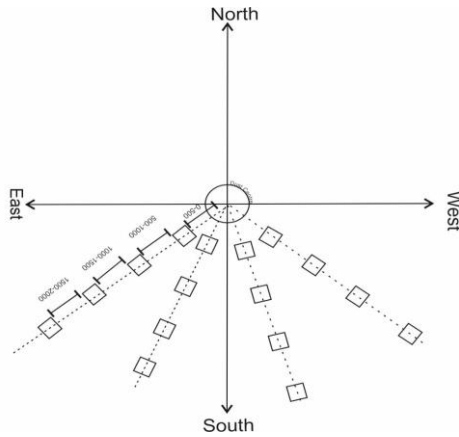
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434 **Table 3.** Changes of seed banks and sheep fescue, which is dominate plant, plant height and
 435 bunch size depending on years and dust emitting centre in the experimental area.¹

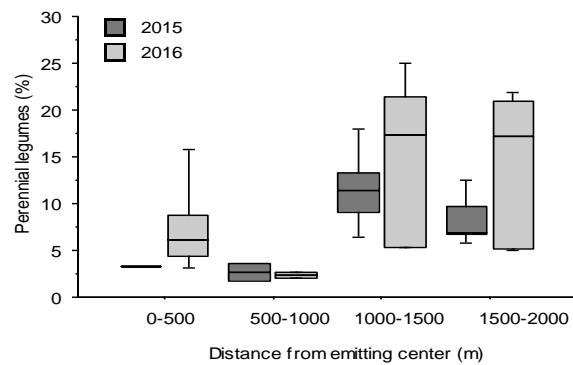
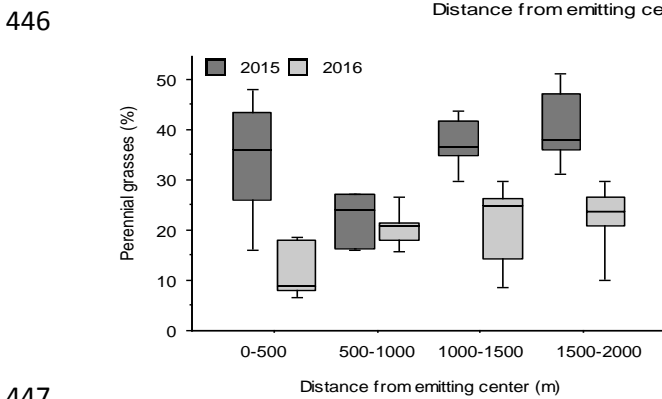
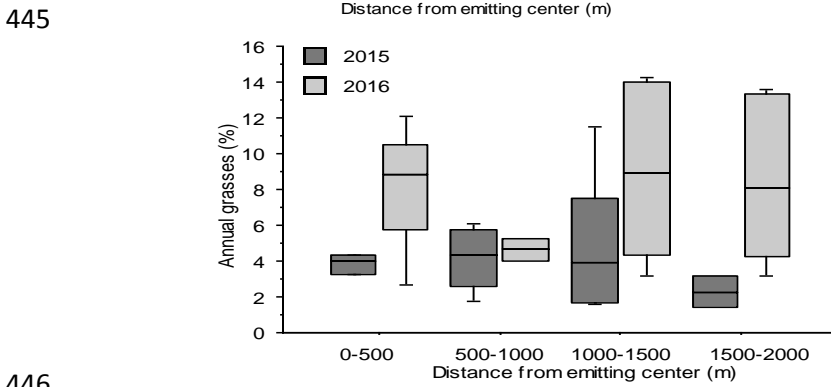
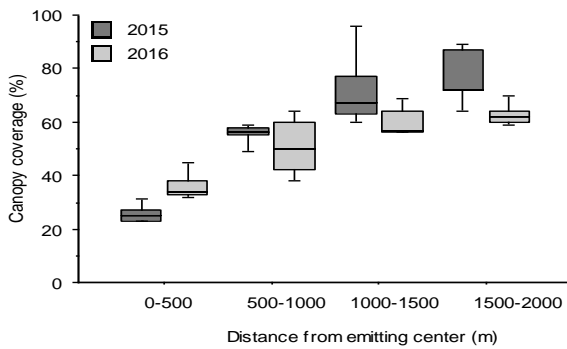
	Total	AG	PG	AOF	POF	Height	Bunch
Year (Y)							
2015	1388.7	206.7	290.2 B	539.0	690.7	32.3	5.5
2016	1628.6	221.9	481.4 A	600.8	687.2	32.5	5.9
Distance (D)							
0-500	607.0 C	200.3	227.3 B	263.5 B	256.3 B	22.9 C	2.1 C
500-1000	1044.2 B	155.0	261.9 B	444.9 B	456.8 B	31.1 B	2.8 C
1000-1500	1481.8 B	165.3	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

436 ¹Values followed by capital in a column shows significantly differences at $P < 0.05$, $P < 0.1$ and $P < 0.01$ levels,
 437 respectively, using Bonferroni/Dunn multiple range test. ns: No statistical difference at $p < 0.05$, $p < 0.1$ and $p <$
 438 0.01. *: Statistical difference at $p < 0.05$. **: Statistical difference at $p < 0.1$, and ***: Statistical difference at $p <$
 439 0.01.

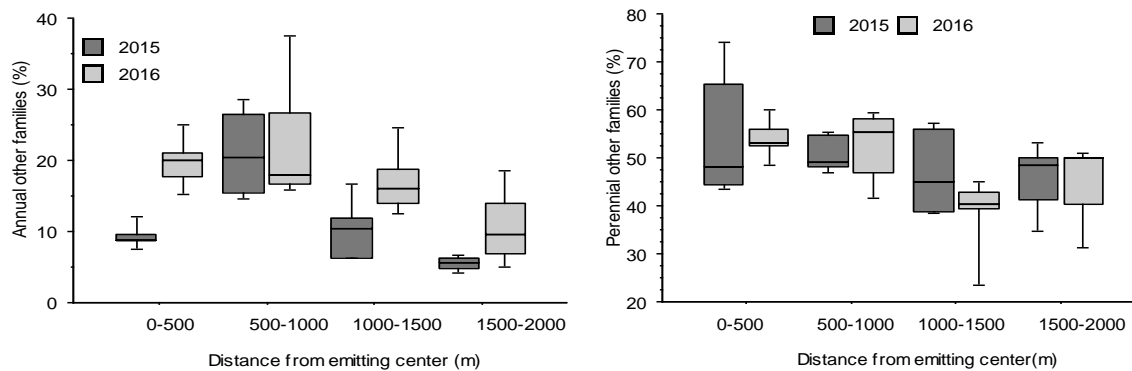
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441 **Figure 1.** Experimental designs of vegetation survey and seed bank examination based on
 442 distance from the dust emitting centre.
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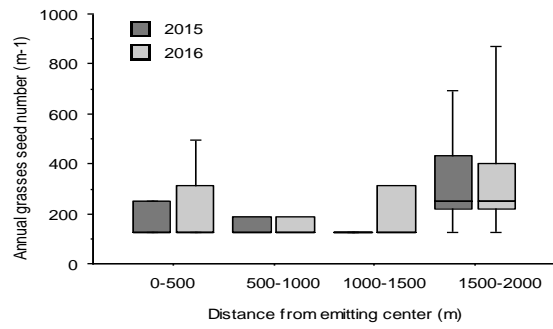
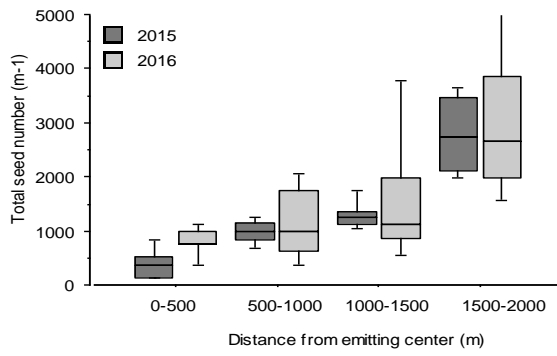


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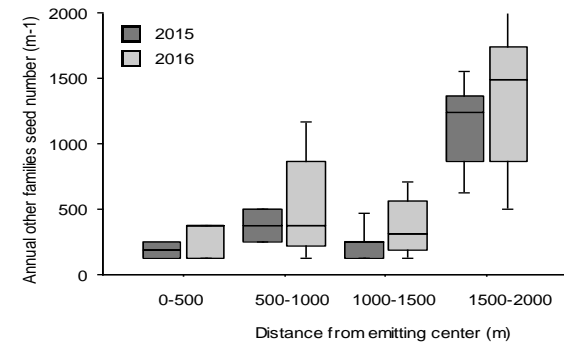
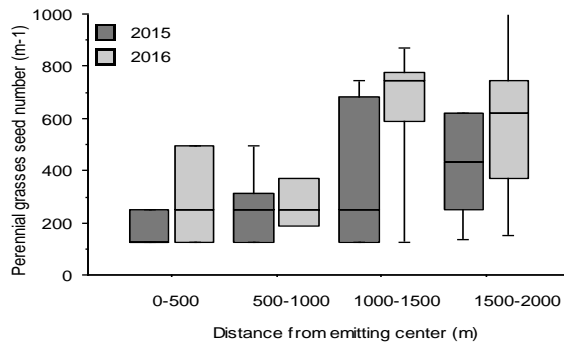
448
 449 **Figure 2.** Variation of canopy coverage, functional groups (Annual grasses, Perennial grasses,
 450 Perennial legumes, Annual other families and Perennial other families) with aboveground
 451 vegetation distance from dust centre.
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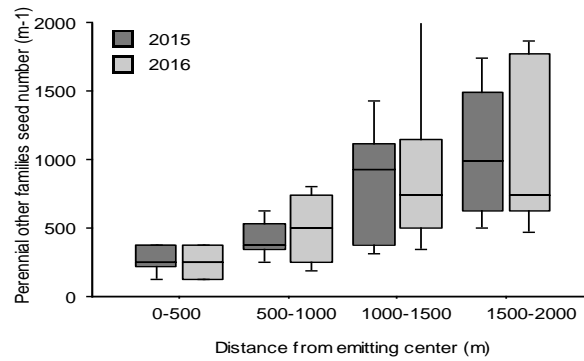
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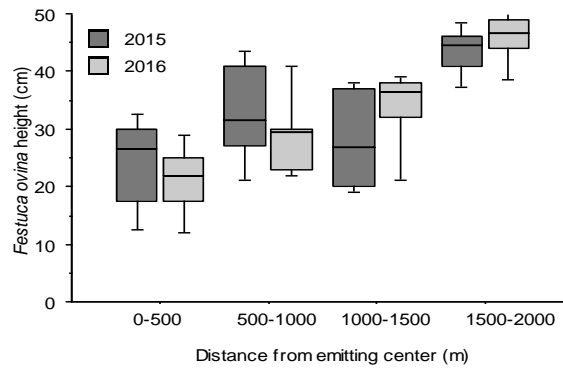


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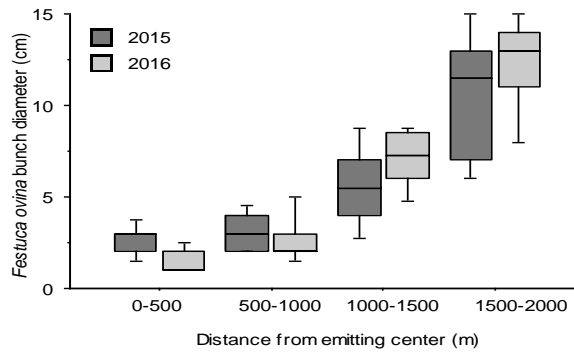
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Figure 3. Variation of seed bank with distance from dust centre.



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