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Quantifying aggregate stability of a clay soil under annual forage crops

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Abstract

This study explored the influence of 10 annual forage legumes belonging to the *Lathyrus* and *Vicia* genera on wet aggregate stability (WAS) and dispersion ratio (DR) indices of a clay soil. Five *Lathyrus* and five *Vicia* species were sown in autumn. Seed-to-seed and row-to-row distance was maintained at 5 cm and 20 cm, respectively. The experiment was planned in a randomized block design with three replications. After 90 d following seed harvest, soil cores were collected from two depths (0–15, 15–30 cm) in each plot and WAS and DR were determined. Annual forage legumes increased WAS of the soil but decreased the DR index. The WAS and DR values were affected at level of $p < 0.001$ by genus, species, and soil depth. Values of WAS and DR of the control plots without plant on the average were found to be 44.5% and 9.3% for 0–15 cm, and 41.2% and 10.1% for 15–30 cm, respectively. For 0–15 cm depth, the highest WAS (77.7%) and the lowest DR (6.4%) values were found in *L. sphaericus* L. (wild) plots. For 15–30 cm depth, the highest WAS value (62.6%) was obtained in *L. annuus* L. (wild) plots and the lowest DR value (6.7%) was in *L. sativus* L. (Gurbuz-2001) plots.

Key words: soil / wet aggregate stability / dispersion ratio / forage legumes

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1 Introduction

A considerable part of soil loss in Mediterranean climate is due to erosion associated with relatively few rainstorms. As much as half of the annual amount of soil eroded can stem from only a couple of high-intensity rain events (*Rickson*, 2006). These heavy rainfalls cause erosion of bare soil, even if the soil has high clay content. Agricultural soils in Turkey are particularly susceptible to erosion after harvest in August until soil cover has been re-established in November. Severe rain storms in these months negatively affect physical properties of the bare soil by deteriorating aggregates and clogging macropores leading to an increased erosion risk. Choosing a crop that increases aggregate stability during growing season is one strategy to decrease the risk for post-harvest erosion.

Previous studies already reported on the positive effects of plant cover and aggregate stability (*Rachman* et al., 2003; *Gulser*, 2006; *Gol* and *Dengiz*, 2008) expressed as wet aggregate stability (WAS) and dispersion ratio (DR). High WAS and low DR values indicate well-structured soil with high aggregate stability and low erodibility. These studies, however, focused primarily on perennial pasture plants. Little is known about the effect of annual forage genera on aggregate stability although annual species are very important for small-scale farms in Turkey, as well as in other regions with Mediterranean climate.

Vicia and *Lathyrus* species are the most important annual forage crops in Turkey and are preferred by small-scale farms because of their short growing season. *Vicia* and *Lathyrus* species are also suitable as winter cover crops providing sufficient plant cover (*Daniel* et al., 1999) and improving the percentage of soil organic matter (SOM) (*Nyakatawa* et al., 2001). Soil-structure improvements associated with legume-based rotations also increase the moisture-holding capacity and drought tolerance of soils (*Goldstein*, 1989).

The objective of this study was to quantify the effects of five *Lathyrus* and five *Vicia* species on aggregate stability of heavy clay top- and subsoil in N Anatolia, Turkey. Aggregate stability was measured in terms of WAS and DR. The overarching goal is to understand (1) how much these annual forage legumes in general increase aggregate stability and (2) how much the individual species increase aggregate stability and therefore decrease erosion sensitivity during precipitation-rich fall and winter months. Results can be applied to locations with similar climate and soil conditions and will be useful to breeders for choosing crops which are both productive and improve soil quality.

2 Material and methods

2.1 Study area

This study was carried out at the experiment field of Agricultural Faculty at Ondokuz Mayis University, Samsun, Turkey (264 972 E, 4 581 185 N, UTM). The climate is under dominant macro–Mediterranean climate with relatively cool winters and hot summers (*Turkes*, 1996). The experimental site is characterized by a slope of 2%, an altitude of 158 m asl, average annual rainfall of 710 mm, average annual tempera-

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ture of 14°C, and relative humidity of 73.8% (annual mean values of 1931–2006) (*Karabulut* et al., 2008).

2.2 Plant selection

Five annual *Lathyrus* and five *Vicia* species were used as plant materials. The names and origins of the 10 selected species are given in Tab. 1. Wild species were collected from natural lands of Samsun and identified by the Agronomy Department at Ondokuz Mayis University. Annual species were selected for this study since they are very important due to their suitability to small-scale farms and need for new annual forage species is higher than for perennial ones in Turkey. Except for *L. sativus*, all the investigated plants were wild species. They were chosen due to their potential for forage breeding with advantageous yield and growth habits for Turkey and similar soil and climate conditions world-wide.

2.3 Experimental design

Plants were sown on November 22, 2006, and harvested for seeds in June and July, 2007. Before sowing, germination tests were carried out, which showed that wild species have a very low germination percentage because of hard seed coat. Thus, seeds of the wild species were mechanically softened before sowing by using sandpaper. Seed-to-seed and row-to-row distance was maintained at 5 cm and 20 cm, respectively, with 100 seeds per m^2 and a plot area of 6 m^2. Ten different forage plant species were laid out in a randomized block design with three replications. One plot per replicated was left unplanted as a fallow control. During the vegetation period, no fertilizer was applied.

2.4 Soil characterization

The soil at the experimental site is classified as Vertic Hapludoll (*USDA*, 2003). Soil samples were taken from 0–15 (topsoil) and 15–30 cm depths (subsoil) 90 d after plant harvest using a corkscrew-shaped soil drill. We determined the physical and chemical properties given in Tab. 2. Two different sampling depths were selected since root densities of annual forage crops are different for top- and subsoil (*Steingrobe,* 2005). Particle-size distribution was determined by the hydrometer method (*Bouyoucos*, 1951), organic-C content by the Walkley-Black wet-digestion method (*Kacar*, 1994), and CEC by 1N NH_4-acetate extraction method (*Kacar*, 1994). Contents of $CaCO_3$ content were measured using Scheibler calcimeter (*Rowell,* 1996). Soil reaction (pH) and electrical conductivity (EC) in 1:1 soil-to-water suspension (w/v) were determined according to standard methods by *Pansu* and *Gautheyrou* (2006). Field capacity and permanent wilting point were determined at 0.33 and 15.0 bar pressure, respectively, following *Klute* (1986).

Table 1: Plant materials and their notation in this paper.

Genus	Species	Notation
Lathyrus	*L. sativus* L. (IFSL 512 sel 565)	L1
	L. sativus L. (Gurbuz-2001)	L2
	L. annuus L. (wild)	L3
	L. hirsutus L. (wild)	L4
	L. sphaericus L. (wild)	L5
Vicia	*V. sativa* L. (wild)	V1
	V. lutea L. (wild)	V2
	V. villosa L. (wild)	V3
	V. narbonensis L. (wild)	V4
	V. bithynica L. (wild)	V5

Table 2: General properties of the experimental soil at 0–15 and 15–30 cm depths.

Property	Description	
	0–15 cm	15–30 cm
Clay / g kg^{-1}	563	547
Silt / g kg^{-1}	222	302
Sand / g kg^{-1}	215	151
Textural class	C	C
pH / 1:1 soil to water	6.45	6.46
$EC_{25°C}$ / dS m^{-1}	0.052	0.050
Organic C / g kg^{-1}	13.6	11.3
$CaCO_3$ / g kg^{-1}	19.1	38.0
Cation-exchange capacity / cmol (Na^+) kg^{-1}	22.7	21.8
Soil moisture at 0.33 bar / m^{-3} m^{-3}	0.44	0.44
Soil moisture at 15 bars / m^{-3} m^{-3}	0.33	0.32

The soil is characterized by its high clay content of 563 and 547 g kg^{-1} at 0–15 and 15–30 cm depths, respectively. Chemical and physical properties (Tab. 2) are very similar for both depths, indicating that differences in WAS and DR values predominantly reflect differences in soil structure caused by the different plant species.

2.5 Aggregate-stability measurements

WAS was determined by wet-sieving analysis (*Kemper* and *Rosenau*, 1986). DR was determined according to *Lal* (1988). ANOVA was done for WAS and DR values using the $LSD_{0.05}$ test implemented in the *TARIST* (1994) statistics package.

3 Results and discussion

In this study, we found that annual forage crops significantly increased WAS (Fig. 1) and decreased DR of the soil (Fig. 2). Values of WAS of the control plot were found at 44.5% for 0–15 cm, and at 41.2% for 15–30 cm soil depth. The highest WAS value of 77.7% was determined for *L. sphaericus* L. (wild) at 0–15 cm depth. For 15–30 cm depth, the highest WAS value (62.6%) was obtained for *L. annuus* L. (wild). The DR values of the control plots were 9.3% for 0–15 cm and 10.1% for 15–30 cm. The lowest DR values of 6.4% and 6.7%, respectively, were determined for *L. sphaericus* L. (wild) at 0–15 cm and *L. sativus* L. (Gurbuz-2001) at 15–30 cm depth, respectively.

Table 3: LSD comparison for WAS and DR among forage plant varieties (Notations were are given in Tab. 1).

		Varieties											
	Soil depths, cm	L1	L2	L3	L4	L5	V1	V2	V3	V4	V5	Control	$LSD_{0.05}$
WAS / %	0–15	68.30 cd	68.99 c	65.77 de	67.27 cde	77.73 a	64.74 e	73.10 b	59.40 f	61.00 f	67.73 cd	44.47 g	2.801
	15–30	58.40 bcd	61.18 ab	62.60 a	57.70 cde	57.80 cde	58.87 bcd	55.40 e	59.23 bcd	57.27 de	60.27 abc	41.23 f	2.801
DR / %	0–15	6.73 bc	6.77 c	6.69 abc	7.67 f	6.40 a	7.13 d	6.52 abc	8.28 g	7.14 d	6.55 abc	9.30 h	0.293
	15–30	6.97 a	6.73 a	8.23 b	8.27 bc	9.28 f	8.97 e	8.63 d	8.53 cd	9.71 g	8.16 b	10.07 h	0.293

ANOVA results showed that WAS and DR were significantly affected by the individual species ($p < 0.001$). The effect of each species was also different for top- and subsoil. Details on the $LSD_{0.05}$ comparison test are given in Tab. 3. For the topsoil, the ranking of plant species increasing WAS was found as L5 > V2 > L2 > L1 > V5 > L4 > L3 > V1 > V4 > V3. Similarly, the ranking of plant species decreasing DR yielded L5 > V2 > V5 > L3 > L1 > L2 > V1 > V4 > L4 > V3. According to WAS, L5 (*L. sphaericus* L. [wild]) and V2 (*V. lutea* L. [wild]) are the two most effective species for improving soil stability in the topsoil, whereas V3 (*V. villosa* L. [wild]) was the least effective. The *Lathyrus* genus also seem to be more effective than the *Vicia* genus. Ranking for WAS values (L3 > L2 > V5 > L1 > V1 > V3 > L4 > L5 > V4 > V2) and DR values (L2 > L1 > V5 > L3 > L4 > V3 > V2 > V1 > L5 > V4) from the subsoil showed no "winner" but a clear trend that *Lathyrus* genus are more effective than *Vicia* genus in terms of improvement of soil structural stability in the subsoil.

From these results, we conclude that *L. sphaericus* L. (wild) and *V. lutea* L. (wild) are the most effective species in increasing aggregate stability and decreasing erosion sensitivity in the topsoil. *Lathyrus sativus* L. (Gurbuz-2001) seems to perform best in increasing aggregate stability of the subsoil. We attribute the differences in efficiency of the different species to their different root densities in top- and subsoils. This study clearly shows that aggregate-stability improvement by annual forage plants strongly depends on the plant species.

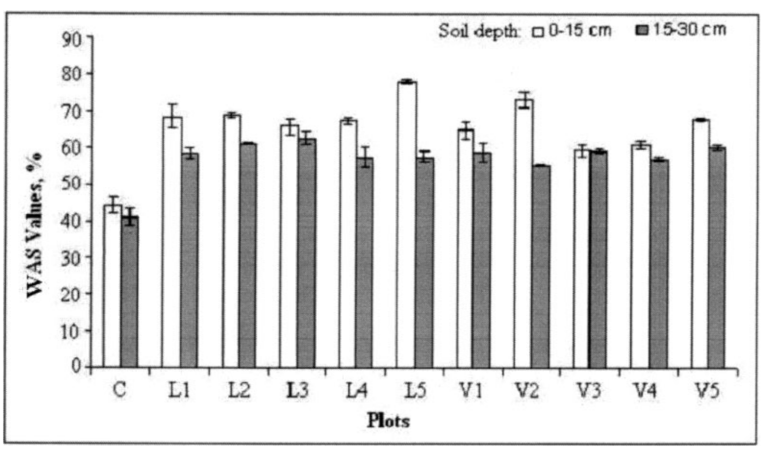

Figure 1: Changes in WAS among plant varieties (Notations are given in Tab. 1).

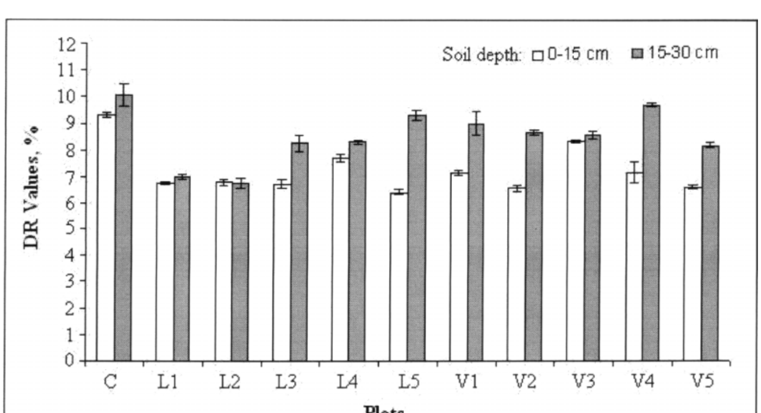

Figure 2: Changes in DR values among plant varieties (Notations are given in Tab. 1).

4 Summary and conclusions

For Turkey, annual *Lathyrus* and *Vicia* species are very important forage crops for small-scale farms used for animal feeding. It is clearly known that annual legume forages have positive effects on soil physical properties, but these effects vary depending on plant species and ecological conditions. Due to the fact that annual forages have a short growing season their effects on aggregate stability are considered minor compared to similar effects of perennial plants. Therefore, a particularly careful selection of suitable annual forages is important to improve soil quality besides their yields for specific ecological conditions. In the present study, we investigated effects of selected *Lathyrus* and *Vicia* species (cultivar or wild) on aggregate stability of a heavy clay soil in N Anatolia. Our results show that the annual *L. sphaericus* L. (wild) significantly increased wet aggregate stability (WAS) by 73% and decreased dispersion ratio index (DR) by 45% in surface soil. On the other hand, *V. lutea* L. (wild) significantly increased WAS by 63% and decreased DR by 43% in surface soil. Both are indicators for a significant increase in aggregate stability and subsequent decrease in erosion sensitivity due to the *L. sphaericus* L. (wild) and *V. lutea* L. (wild) species. In subsoil samples, *L. annuus* L. (wild) increased WAS by 52% and *L. sativus* L. (Gurbuz-2001) decreased DR by 50% when compared to values of the control plot. Although all 10 species show a significant improvement of soil-aggregate stability compared to the soil of a nontreated control plot, the effects vary for the different species. In conclusion our study shows that *L. sphaericus* L. (wild), *L. sativus* L. (Gurbuz-2001), and *V. lutea* L. (wild) species could be used for combating soil erosion by water in N Anatolia as well as for similar climate conditions world-wide (heavy rainfall in autumn and winter, low temperatures during winter, and high temperatures during summer months).

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