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Lentil Crop Rotation and Green Manuring Effects on Soil Structural Stability and Corn Yield in Different Soils in Central Greece

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RESEARCH ARTICLE

Abstract

Grain legume production contributes widely to ecosystem services and have the potential to improve soil structure, increase soil organic carbon and reduce soil compaction. Growing more legumes in future requires changes to the cropping system, the sequence, and crop management. The objectives of this study were to examine the effects of lentil cover cropping managements on (i) soil structure and (ii) subsequent corn yield, in two different soil types. Experiments were carried out on a clayey and on a sandy soil, following a RCB design, for two years. Three legume managements were tested before growing corn (rotation, incorporation as green manure, no cover crop). For assessing soil structure stability the instability index, β was used. Corm productivity was determined by field samplings. Both lentil management, had significant effect on the instability index β. Stability of soil aggregates was enhanced during spring and reduced during autumn, regardless of the lentil pre-treatment, confirming the seasonal variation of soil structure stability. Legume rotation and green manure positively affected corn kernel yield in both soils. Results suggest that lentil rotation or green manuring has a positive effect on soil structure on both sandy and clay soils, leading to higher yields for subsequent corn crop.

Keywords: corn, lentil, rotation, soil stability

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INTRODUCTION

Crop diversification in classical monoculture extensive agrosystems is a strategy increasingly promoted, as it is seen as adequate for a more balanced nutrient management, decreased pest and disease pressure, reduced soil degradation risks and adaptation to climate change (European Union, 2013; FAO, 2011, 2016). Maintaining current crop yield, sustaining soil quality and delivering ecosystem services are encouraged with an adoption of legume in rotation (different crops in the same area in different years) and multiple cropping (different crops in the same area in different seasons within the same year) (St Luce et al. 2015). Positive effects of legume rotations and multiple cropping on subsequent crops yield have been reported by several authors (Tigka et al. 2013; Smith et al. 2016), and it is primarily due to their ability to fix atmospheric nitrogen (N) through biological nitrogen fixation, and thus provide extra available N (Unkovich et al. 2008). The influence of legumes on soil fertility is normally evident after a long period

(Kirkegaard and Ryan, 2014). However, the choice of legume that will result in sustainable improvements in crop productivity is a complex matter since the selected legume has to be well adapted to local biophysical constraints such as soil type or climatic conditions, and to the particular cropping system (e.g. organic or conventional) (Peoples et al. 2009).

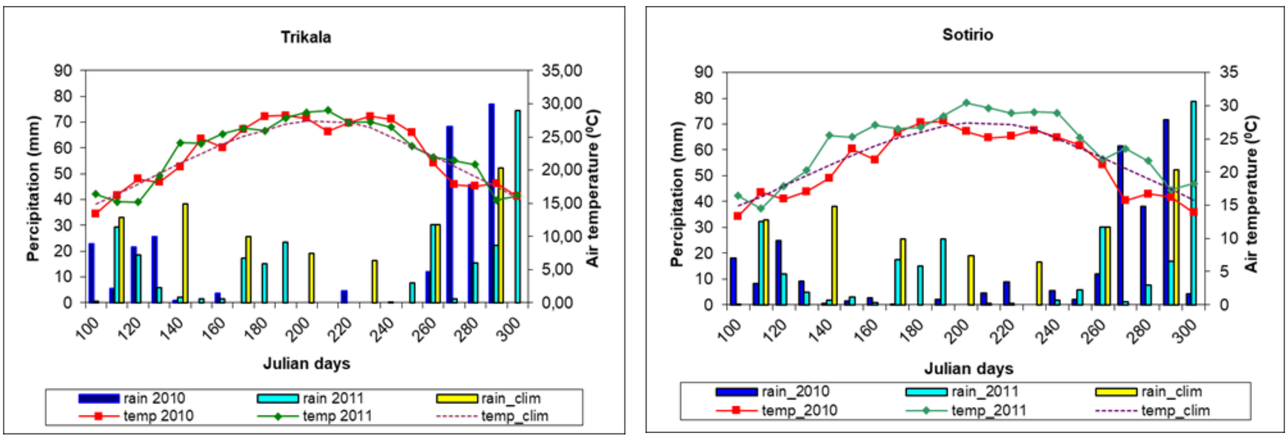
Agricultural soil management can also interact with natural processes of soil organic matter stabilization and aggregation, and therefore needs to be considered when assessing the consequences of introducing new crops in rotations (Oliveira et al. 2019). Soil quality is closely related to soil structure and many environmental problems found in intensively cultivated soils such as erosion, desertification and degradation stem from soil degradation. In addition, soil activities are highly dependent on the quality of the soil structure, with the optimum being that which allows the soil to be used for multiple uses (Dexter, 2002). Aggregate stability, among others, is used to determine soil structure changes caused by agricultural activities (Moran and McBratney, 1992).

Aggregate stability is an important measurement of soil health and responds positively to N fertilization (Campbell et al. 1993), no-till (Helgason et al. 2010), and cover crops (García González et al. 2018). The stability of the aggregates of a soil controls the direct percolation of water from the surface layers and the creation or non-surface crust (Chan and Mead, 1988). It is also considered as an effective indicator of soil erodibility (Dunne et al.1991) especially in Mediterranean regions characterized by intense storms (Barthès and Roose, 2002). Improving the stability of aggregates and arguably the structure of a soil results in more favorable plant growth as root system development is enhanced and plant uptake of water and available soil nutrients is increased (Bronick and Lal, 2005). In this framework, we aimed to test the following hypothesis with this study: (i) introducing grain legumes such as lentils, that are widely cultivated in the Mediterranean area, in a crop rotation with maize will cause a response in aggregation in the short-term; (ii) this change in aggregation will be evidenced in week sandy soils as well as in high productivity clayey soil; and (iii) assess the effect of different management of preceding legume crop, considering two different practices, on soil aggregation and the yield of the subsequent maize crop.

MATERIALS AND METHODS

A three year field experiment was carried out following a RCB design, involving the cultivation of corn (*Zea mays,* cv PR36k67 - FAO 430) as main crop after the cultivation of lentils (*Lens culinaris* L., cv Samos), as cover crop in the period 2009-2011, comprising three legume cropping managements (I= incorporated into the topsoil upon 50% anthesis, H=harvested before the sowing of maize, C= control, no cover crop). The results in this paper refer to the second year and third year of the experiment.

The study area was consisted by two experimental fields in two locations of the Thessaly Plain, with similar climate (Figure 1) but different soil characteristics. The first experimental field was located in the Trikala area (coordinates: 39º32′17.08′′N, 21º46′19.17′′E, elevation 120 m ASL). The soil was Typic Xerofluvent, with a calcareous sandy-clayey-loamy texture (average soil particle size distribution: clay 22%, silt 18%, sand 60%), pH of 7.7, and organic matter content of 1.3% in the topsoil. The second field was located in the Sotirio area (coordinates: 39º30′02.85′′N, 22º42′50.37′′E, elevation 60 m ASL), and the soil was silty-clayey to clayey, classified as Vertisol, with average soil particle size distribution of clay 63%, silt 35%, sand 2%, pH of 7.9, and 1.7% organic matter content in the topsoil.



(a) (b)

Figure 1. Temperature and precipitation (10-days mean values) occurring during the growing period of maize in 2010 and 2011, in Trikala (a) and Sotirio (b) area. Climatic air temperature (dashed line) and monthly total precipitation are also illustrated (National Meteorological Service, 1955-2010)

Planting arrangement was 75 cm x 20 cm for maize, while for lentils 90 kg/ha of seed was sowed with an Amazon seeder. Plots size was 9 m^2, consisted of four rows and an average plant density for maize of 6.66 plants m^{-2}. Control plots were left fallow (no cover crop) during winter, while the same growing techniques and irrigation schedule were followed for all plots. Fertilization was applied in two doses. The first was applied at sowing as basal dressing with 80 kg N ha^{-1} (nitrate form), 50 kg P ha^{-1} and 50 kg K ha^{-1}. The second dose with additional 120 kg N ha^{-1} (ammonium form) was applied on the onset vegetative phase of maize, when plant height was approximately at 50 cm. The amount of dry biomass of lentils incorporated in the topsoil was measured directly by means of destructive sampling upon full flowering each year. Maize was grown under optimum water and nutrient availability, and no macro-nutrient deficit, or water stress, were observed throughout the crop cycle.

At harvest, all plots were sampled (1.5 m^2 of the two middle rows of 1 m each), for yield components. All plant samples were cut near the soil surface and the belowground fractions were left in the field. Dry matter of seed by drying sub-samples in a convection oven at 70°C until constant weights.

To estimate the stability of the soil structure, the soil instability index β (Valmis et al., 1988) was used, which is an indicator of the relative water stability of soil aggregates, and is based on a relatively fast calculation method with reliable results. Experimental plots and sampling points remained stable during all three years. To estimate the initial stability of the soil structure, no separate sampling was done but the data from the control subplots were used. The values of β vary between 0 and 1, where β=0 in perfectly stable soils and β=1 in completely unstable soils. All measured and derived data (from the calculations mentioned) were subjected to analysis of variance (ANOVA), using SPSS 22 software, following the experimental design. As test criterion for detecting differences between means the $LSD_{0.05}$ was used (Steel & Torrie, 1982).

RESULTS AND DISCUSSIONS

Soil instability index β

In the sandy soil of the area of Trikala, as can be seen in Table I. (a), both cover cropping managements had a statistically significant effect (P<0.05 and P<0.01) on means of the instability index $^{\beta}$ and by extension to the stability of the aggregates compared to the means of the index β corresponding to the control blocks. The statistically significant effect (P<0.05 and P<0.01) was observed in all soil samples on both experimental years, despite the small decrease in β values observed. A similar, significant effect (P<0.05) of the managements with lentil on soil structure was also found in the clay soil of the Sotirio area. Instability index β values are smaller in the clayey soil compared to the sandy soil, confirming the reliability of the index as clayey soils are considered soils with increased stability.

The β index values were calculated before and after the end of the lentil growing season, in all experimental years. As schematically depicted in Figure 2a in the sandy soil of Trikala, the stability of soil aggregates was enhanced during the spring measurement and decreased during the autumn measurement in all three years regardless the lentil pre-treatment, confirming the seasonal variation of the stability of the structure, but also the sensitivity of the soils to erosion during the autumn months due to the presence of heavy rainfall (Roth et al.,1987; Bajracharya et al., 1992; Van Dijk et al., 1996; Valmis et al., 2005). In addition, the incorporation of lentil into the soil resulted in reduced values of the index β compared to those recorded in the control plots, in all measurements. A greater reduction was recorded in the case of the lentil cover crop (Figure 2a).

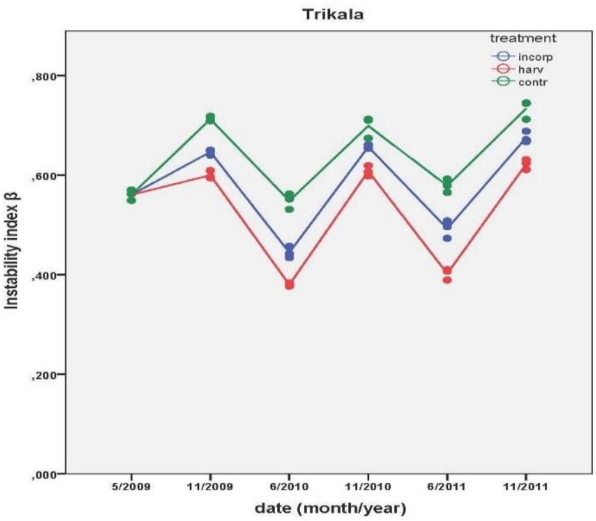
The decrease in β values in sandy soil implies an increase in structure stability, confirming a number of previous studies that support that increasing soil organic matter results in an increase in structure stability (Chirinda et al., 2010; Hargreaves et al., al. 2008; Papini et al., 2011).

Table 1. Variation of the values of the instability index β in the plots of lentil green manuring (Incorporation), lentil cover crop (Harvest) and the control (Control) in the two study areas.

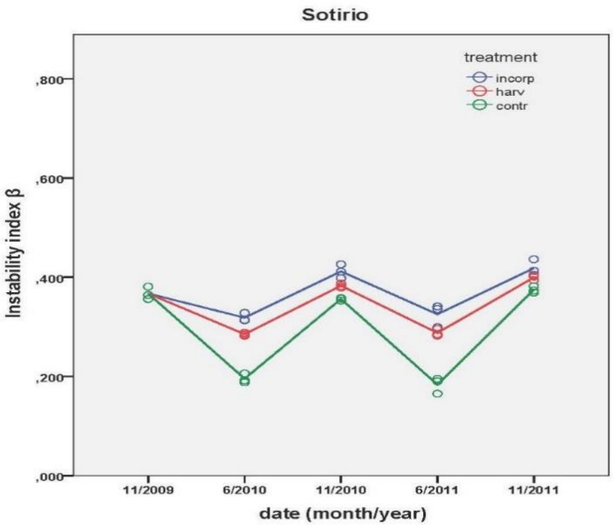
Trikala area (sandy soil)					Sotirio area (clayey soil)				
Instability index β (0≤ β ≤1)					Instability index β (0≤ β ≤1)				
Date	**Incorporation**	**Harvest**	**Control**	**LSD [a]**	**Date**	**Incorporation**	**Harvest**	**Control**	**LSD [a]**
11/2009	0.64633	0.59967	0.71233	0.047**	**11/2009**	0.36700	0.36700	0.36700	-
06/2010	0.44433	0.37967	0.54833	0.064**	**6/2010**	0.31833	0.28500	0.19533	0.033*
11/2010	0.65667	0.60767	0.69867	0.042**	**11/2010**	0.41167	0.38267	0.35600	0.026*
06/2011	0.49233	0.40200	0.57867	0.086**	**6/2011**	0.32533	0.28767	0.18333	0.037*
11/2011	0.67533	0,62200	0.73367	0.053*	**11/2011**	0.41800	0.39933	0.37467	0.018*
Means	0.57922	0.52856	0.63867			0.36807	0.34433	0.29527	

Note: [a] LSD: least significant deference σε P<0,05(*) και P<0,01(**)

Soil organic matter that is enhanced by the incorporation of legumes into the soil increases the cohesion of sandy soils and promotes the creation of stable aggregates by improving soil porosity, either through bonds developed between the soil tiles and organic polymers or from the retention of soil resources in the well-developed root system (Chenu et al., 2000, Tigka et al., 2021). Furthermore, the increase in organic matter in sandy soils increases the ability to retain moisture and nutrients at a suitable depth so that they can be absorbed by the root system of crops (Degens et al., 2000), increasing their yield and favoring their growth, which is in agreement with the findings of the present study.



(a)



(b)

Figure 2. Seasonal variation of the soil instability index *β* in the plots of lentil green manuring (Incorporation), lentil cover crop (Harvest) and the control (Control) in the sandy soil of Trikala area (a) and the clayey soil of Sotirio area (b).

On the contrary, enhancing the amount of soil organic matter through lentil cover croping in the case of clay loam soil resulted in an increase in β values compared to the values recorded in the control, as organic matter improves the stability of clay soils by increasing the elasticity and reducing the plasticity and cohesiveness of the specific soils (Bayu et al., 2005; Verkler et al., 2009; Papini et al., 2011). It is therefore expected that β values move away from zero with increasing organic matter. Furthermore, clayey soils face strong problems of surface crust formation and cracks and the strengthening of the soil organic matter which transmits its hydrophobic characteristics to the soil aggregates, thus reducing their wettability; delaying the rate of their wetting and fragmentation is an essential solution (Sullivan, 1990; Sánchez-Navarro et al., 2019).

Maize grain yield

Maize grain yield when grown as a subsequent crop after lentil cover cropping managements is presented in Table 2. In all cases green manuring with lentil or cultivation as a cover crop, significantly affected grain production of maize, on both experimental years, presenting particularly high production. In the control plots, even with the addition of high N fertilization level, grain yields were significantly lower. It is noteworthy that in the case of clay loam soil, the production achieved in the sub-plots of the incorporation were very high, which is due both to the improvement of soil fertility (Shen and Chu, 2004; Dahmardeh et al. 2010) as well as to the ability of legumes to bind atmospheric N_2 and offer it to the successive crop through its mineralization (Pypers et al. 2005). Maize following leguminous crops can show improved root growth and root vigor, which can have consequences for the uptake of nutrients and water (Beslemes et al. 2013). So cover cropping could be a potentially useful practice for obtaining comparable or even higher maize yields with less fertilizer N. This is reflected by different yield responses of maize in monoculture and maize grown in rotation to N fertilization (Fisk et al. 2001). Increased maize grain yield after cover cropping managements could also be related to improved soil structure characteristics. Adeli et al. (2020) reported that cover crops usage reduced soil bulk density and Haruna et al. (2018) on a silt loam soil that cover crops improved the proportion of macropores by 30%. At the same time, the introduction of cover crops into the crop rotation cycle may trigger increased mineralization and CO_2 emissions at the early stages due to the increased microbial activity. Over time, microbial immobilization increases and, thus, an increase in soil organic matter. As such, Sainju et al. (2008) suggested that soil organic content could be conserved and/or maintained by reducing losses through mineralization and erosion.

Table 2. Maize grain yield when grown as a subsequent crop after lentil cover cropping managements

	Maize grain yield (tn ha^{-1})			
	Sandy soil (Trikala)		Clayey soil (Sotirio)	
	2010	2011	2010	2011
Incorporation	11.63^{a}	9.65^{d}	18.63^{a}	16.23^{d}
Harvest	11.33^{b}	9.38^{e}	17.82^{b}	15.44^{e}
Control	10.6^{c}	8.87^{f}	15.24^{c}	13.68^{f}
Means	11.19	9.30	17.23	15.12

Note: Different letters between treatments denote significant differences (LSD test, $P < 0.05$).

CONCLUSIONS

Results demonstrated that cover cropping systems, especially involving the use of lentils as cover crop or green manure, deserve increased attention and tent to be superior to the traditional monocrop systems in quantitative and qualitative characteristics. They substantially improved soil structure, resulting also in incretion of the final yield productivity of maize, especially in the light textured soils with low inherent fertility.

Author Contributions: D.B., N.D. Conceived and designed the experiment; D.B, E.T. Collected the data; E.T., I.K., D.V. Contributed data and analysis tools; D.B., E.T., I.R. Performed the analysis; D.B, E.T., I.R. Wrote the paper.

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Conflicts of Interest

The authors declare that they do not have any conflict of interest.

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