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Effect of Lentil Cover Cropping on Soil Hydraulic Properties and Subsequent Crop Productivity in Two Soil Types in Central Greece

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RESEARCH ARTICLE

Abstract

Agricultural management practices can significantly affect soil hydraulic properties and processes in space and time. Cover crops are described as “crops grown primarily for the purpose of protecting and improving soil between periods of regular crop production”. They have long been valued for their soil conservation benefits, including reducing erosion, increasing infiltration, and improving soil health. Experiments were carried out on a clayey and on a sandy soil, following a RCB design, for two years, to examine the effects of various lentil cover cropping managements on soil hydraulic properties and subsequent corn yield. Three legume managements were tested before growing corn (rotation, incorporation as green manure, no cover crop). Soil hydraulic properties were assessed with the equation I= S*t -1/2+ Ktr*t + d. Corm productivity was determined by field samplings. Green manuring and rotation with lentil, lowered the Infiltration rate as well as the Hydraulic conductivity in the sandy soil, suggesting less irrigation water losses and higher water exploitation for the subsequent crop. On the contrary, for the clay soil, only Hydraulic conductivity of transiting zone was affected and especially during springtime. Legume rotation and green manure positively affected corn kernel yield in both soils.

Keywords: corn, lentil, soil hydraulic properties

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INTRODUCTION

Agricultural management practices can significantly affect soil hydraulic properties and processes in space and time. These responses are coupled with the processes of infiltration, runoff, erosion, chemical movement, and crop growth (Green et al. 2003). The quantity, kind, and method of applying organic materials to the soil in a cropping system are known to have a significant effect on the physical characteristics of the surface soil and on nutrient recycling (Zeleke et al. 2004) . The effect of soil organic matter on soil structure is well documented and has been shown to influence soil water infiltration (Ghuman and Sur, 2001) and soil water regime (Sharma and Buhushan, 2001). The growing demand for land on a scale parallel to the population which made the old traditional shifting cultivation method involving cultivation of a parcel of land once followed by fallowing with land use factors unrealistic suggest use of short fallow periods with legumes or grasses to keep the soil healthy (Udom and Omovbude, 2019). 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). Other studies focused on soil hydraulic properties. For example, Celette et al. (2008) measured an increase in soil water infiltration under cover cropping and also observed an enhancement in soil aggregate stability, whereas Ward et al. (2012) or Basche et al. (2016) reported an increase in soil water holding capacity when cover crops were used.

Sorptivity is another important soil parameter, strongly corellated to soil type and management. On well-aggregated soils, the water transmission characteristics between the inter-aggregate and intra-aggregate domains often differ (Gerke and Köhne, 2002). Hydraulic parameters are normally measured on the whole soil producing composite hydraulic conductivity values of inter-aggregate and intra-aggregatewater flow. This common approach ignores the boundary values between the two domains. Knowledge of differences in water sorptivity between aggregates and the whole soil is essential to modeling preferential flow and soil matrix flow of water and solutes through the soil (Leeds-Harrison et al. 1994).

Since soil-crop management dynamically affects the soil hydraulic properties and hence the soil water dynamics, then such relantionships, as well as any interferences between crop and hydraulic properties should be identified in order to avoid non sustainable crop managements. The main objective of this study was to assess the medium-term effect of cover crops such as lentils, that are widely cultivated in the Mediterranean area, in a crop rotation with maize, on soil hydraulic properties over the soil profile in week sandy soils as well as in high productivity clayey soil. The secondary objective was to analyse if the change in the soil hydraulic properties could contribute in higher yield of the subsequent maize crop.

MATERIALS AND METHODS

Field experiments were carried out on the Thessaly Plain (Trikala, coordinates: 39º32′16.85′′N, 21º46′19.33′′ E, elevation 120 m ASL and Sotirio, coordinates: 39º30′02.85′′N, 22º42′50.37′′E, elevation 60 m ASL) in 2010 and 2011. The soil at Trikala site has been formed in alluvial materials and classified as Typic Xerofluvent according to USDA Soil Taxonomy (Soil Survey Staff, 2014). The dominant texture was loamy sand with very low nutrient concentration and loose structure and soil particle size distribution is clay 22%, silt 18%, sand 60%, pH=7.2 and organic matter content is 1.7%. At Sotirio, the soil was classified as Vertisol (Soil Survey Staff, 2014), developed also in recent alluvial deposits and represents a large part of central Greece lowland, 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. Design was an RCB, 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, 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.

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 fresh biomass of lentils incorporated in the topsoil was measured directly by means of destructive sampling upon full flowering each year, reaching a mean of 3.1 t ha^{-1}, while on average the crop performed well, producing a final seed production of 1.7 t ha^{-1}. 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.

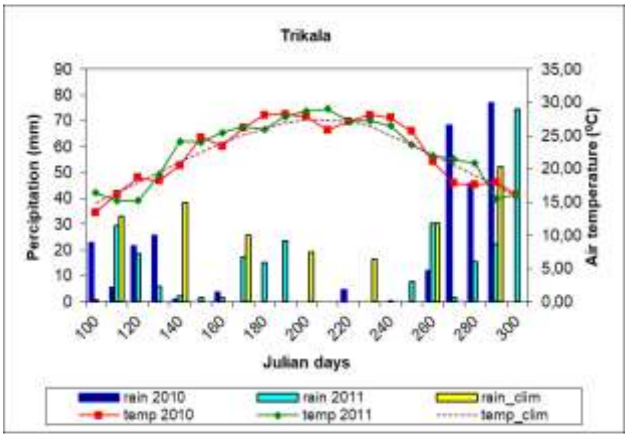
To estimate the infiltration rate (I) and the basic parameters of the infiltrability of a soil, i.e. sorptivity (S) and hydraulic conductivity (K), the double-ring infiltration method was used (Dunne, 1983). The diameter of the inner ring was 280 mm and the outer 540 mm, while the height of the rings was 250 mm, with particularly sharp edges to facilitate their penetration about 50 mm deep into the ground. Just prior to the installation of the rings, the existing plant mass on the site was cut to the ground surface in order to reduce water runoff. The water infiltration rate was measured at times 1, 1, 1, 2, 2, 5, 5, 10, 10 and 15 minutes, while calculations were made using equation of Phillip (1957), as modified according to Danalatos (1993),

$$I= S*t^{-1/2}+ Ktr*t + d \text{ where}$$

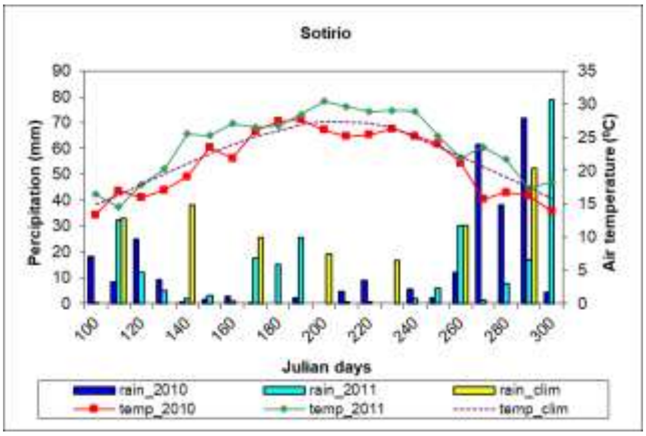
I = cumulative infiltration rate (cm min^{-1})

S = sorptivity (cm $min^{-0.5}$)

K_{tr}= transmission of hydraulic conductivity (cm min^{-1})
t = time (min)
d= constant added to Phillip's equation to reduce the effect of initial turbulence.



(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)

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 hydraulic properties

Green manuring and also cover cropping with lentils resulted in a reduction of the infiltration rate compared to the control managements, as presented in Table 1. This result is desirable in sandy soils, as in this way, greater amounts of available soil water are ensured for plants, utilizing a greater percentage of rainfall or irrigation water, while reducing leaching of agrochemical inputs into deeper soil layers (Blackwell, 2000, Doerr et al. 2000, Kramers et al. 2005). No statistically significant effects (P<0.05) of lentil cover crops were detected regarding sorptivity (S) in the sandy soil, except for the sampling carried out on 05/11, possibly due to the effect of gravity flow, which characterizes the sandy soils and results in the rapid dominance of the K_{tr} term over the S term. On the contrary, the leguminous managements significantly affected (P<0.05), in almost all measurements, hydraulic conductivity (K_{tr}) of the soil, reducing the values, thereby reducing the water permeability of the sandy soil. This result is completely consistent with previous studies (Tarchitzky, 1999; Bhattacharyya et al. 2006). Therefore, cover cropping managements with legumes can improve saturated hydraulic conductivity, attributable to improved structural stability and porosity, which in turn could improve soil water storage, especially in clay soils (Demir and Işık, 2019).

Table 1. Infiltration rate (I), sorptivity (S) and hydraulic conductivity (K_{tr}) in plots of green manuring (Incorporation), lentil cover crop (Harvest) and control (Control) in the sandy soil of the Trikala area. (I= incorporated into the topsoil upon 50% anthesis, H=harvested before the sowing of maize, C= control, no cover crop)

Sandy soil (Trikala area)												
	I (mm h^{-1})				S (cm $min^{-1/2}$)				K_{tr} (cm min^{-1})			
Date	**I**	**H**	**C**	**LSD[a]**	**I**	**H**	**C**	**LSD[a]**	**I**	**H**	**C**	**LSD[a]**
11/2009	9.80	16.59	27.46	17.65**	0.29	0.54	1.57	ns[b]	0.08	0.15	0.19	0.11**
5/2010	16.91	14.49	33.25	18.76*	0.81	0.67	1.34	ns[b]	0.06	0.04	0.21	0.14**
11/2010	7.21	7.85	16.83	ns[b]	0.28	0.33	0.37	ns[b]	0.02	0.01	0.21	ns[b]
5/2011	14.91	13.21	26.85	ns[b]	0.81	0.67	2.51	1,7**	0.02	0.03	0.18	nsb
11/2011	10.45	7.59	12.57	4.99*	0.58	0.37	0.52	ns[b]	0.01	0.02	0.07	0.53**
Means	11.86	11.95	23.39	11.43**	0.55	0.52	1.14	nsb	0.04	0.05	0.17	0.12**

Note: [a] LSD: least significant deference at P<0,05(*) και P<0,01(**), [b] ns: non-significant

Table 2. Infiltration rate (I), sorptivity (S) and hydraulic conductivity (Ktr) in plots of green manuring (Incorporation), lentil cover crop (Harvest) and control (Control) in the clayey soil of the Sotirio area. (I= incorporated into the topsoil upon 50% anthesis, H=harvested before the sowing of maize, C= control, no cover crop)

Clayey soil (Sotirio area)												
	I (mm h^{-1})				S (cm $min^{-1/2}$)				K_{tr} (cm min^{-1})			
Date	**I**	**H**	**C**	**LSD[a]**	**I**	**H**	**C**	**LSD[a]**	**I**	**H**	**C**	**LSD[a]**
5/2010	47.45	47.2	46.89	ns[b]	1.96	1.98	2.56	ns[b]	0.27	0.27	0.11	0.15*
11/2010	75.41	73.73	54.47	ns[b]	2.53	2.22	2.13	ns[b]	0.61	0.67	0.34	ns[b]
5/2011	52.90	54.50	46.98	ns[b]	2.49	1.98	2.64	ns[b]	0.20	0.21	0.06	0.13*
11/2011	37.42	39.86	42.76	ns[b]	1.67	1.64	2.27	ns[b]	0.18	0.21	0.07	ns[b]
Means	53.29	53.84	47.77	ns[b]	2.16	1.95	2.40	ns[b]	0.31	0.34	0.14	0.16*

Note: [a] LSD: least significant deference at P<0,05(*) και P<0,01(**), [b] ns: non-significant

In the clayey soil (Sotirio), infiltration rate values (I) increased in the plots cultivated with legumes, although no statistically significant differences were detected (P<0.05), as can be seen in Table 2. Increasing the infiltration rate in clay loam soils, implies a reduction in aggregate cohesion (Le Bissonnais, 1990), facilitating the movement of water into deeper layers of the rhizosphere (Goebel et al. 2004) and suppressing phenomena such as surface runoff and soil runoff erosion (Hallett et al. 2001, Goebel et al. 2004, Eynard et al. 2004). The inability to detect statistically significant differences is probably due to the specific type of lentil plant biomass which, although with satisfactory biomass yield, its decomposition rate was probably fast, so that it did not significantly affect the soil properties related to the infiltration rate, a conclusion also recorded in other studies (Jiménez et al. 2006, Molina et al. 2007). Cover cropping with lentils, in the case of clayey soil did not significantly (P<0.05) affect sorptivity (sorptivity, S) either, due to the dominance of the side absorbency in the term S in the equation, as it happens in soils where there is a large effect of the capillary effect of water movement (clay soil) (Angulo-Jaramillo et al. 2000). On the contrary, the differences in the hydraulic conductivity of the transiting zone (K_{tr}) between the plots with cover crop and the control plots were significant (P<0.05), especially in the spring months. As detailed in Table 2, in the clay loam soil K_{tr} was increased in all samplings and its average values increased from 0.14 cm min^{-1} in the control plots to 0.34 and 0.31 cm min^{-1} in the plots with lentil cultivation. The increase in K_{tr} with the simultaneous increase in the infiltration rate, confirms the positive effect of legumes cultivation practices such as green manuring and cover cropping in clayey soils, that can lead to an increase in water absorption and movement, a decrease of surface sealing (Chenu et al. 2000) while simultaneously preventing potential environmental problems such as surface runoff and soil erosion (Sumner, 1992; Boix-Fayos et al. 2000).

Maize grain yield

Maize grain yield when grown as a subsequent crop after lentil cover cropping managements is illustrated in Figure 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. It was found that the long-term effects of legume cover crops contributed to increasing soil porosity, saturated hydraulic conductivity, and water retention capacity (Steele et al. 2012), thus protecting its top layer. In turn, increasing water infiltration improves the ability to capture precipitation and store water (Blanco-Canqui et al. 2015). On the other hand, in semi-arid Texas, cover crop as mulch (incorporated on soil surface) increased available soil water by 73% and more than doubled grain sorghum yields (Unger and Vigil, 1998). The availability of soil water at cover crops planting and depletion during growth are always a concern in semi-arid and arid regions. Therefore the potential benefits must be balanced against possible negative effects on the cash crop. Additionally, conservation tillage increases storage of precipitation in the soil through increased infiltration and reduced evaporation. This additional water supplements growing season precipitation and irrigation to meet crop water needs on the semi-arid regions (Clark, 2012).

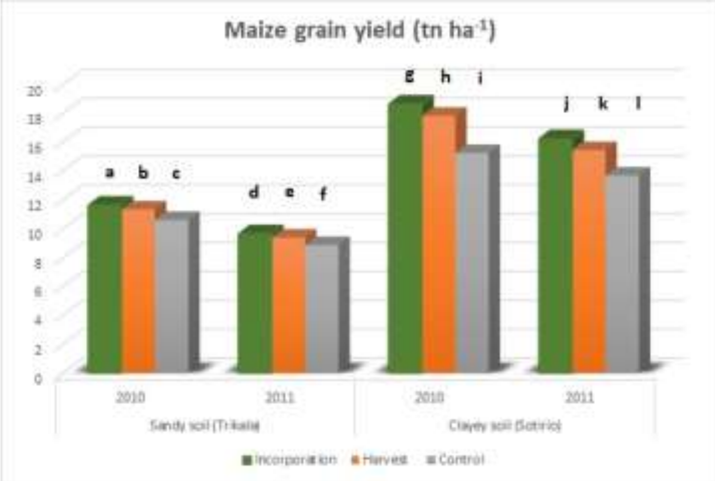


Figure 2. Maize grain yield when grown as a subsequent crop after lentil cover cropping managements
Note: Different letters between treatments denote significant differences (LSD test, $P < 0.05$).

CONCLUSIONS

The lentil cover crops were demonstrated to be a useful tool for improving the soil hydraulic functions of the agricultural system. This improvement could be evidenced in different soil types, based on a more compensated distribution among macro-to micropores, reducing soil compaction and increasing soil water retention and subsequent crop available water. Moreover, the resulting soil could be less prone to runoff and drainage losses, compensating (and even reversing) the possible water competition of the cover crop with the subsequent cash crop. This fact has special relevance in the Mediterranean regions, where water is the most limiting factor in agricultural production.

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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