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Relations between crop rotation with pea and soil structure

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Abstract

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Agricultural practices such as crop rotation affect soil physical, chemical and biological properties. Legumes crop effect has been shown to provide several agro-ecological services as previous crop. The aim of the present field study was to examine the effect of legumes in a crop rotation scenario to the soil structure by incorporating green biomass at the flowering stage of pea. Two field experiments were established in two different soils (sandy and clayey) for three years, where four different nitrogen dressings and three different cultivation practices using pea in rotation were used. Soil samples were collected at two depths (0-20 and 20-40 cm), five times during the experimentation from the establishment till the end. An easier and rapidly soil classification according to the agglomerate stability was used through the coefficient of instability β. It was found that in the sandy soil both green and pea rotation had a significant effect on the improvement of the soil structure resulting from the decrease in the β instability index. Improving the soil structure will also lead to higher yields to the following crop.

Keywords: soil structure; legumes; crop rotation; green fertilization; pea

Introduction

Last decade, many innovative practices have emerged to reduce the impact of agriculture on climate and environment changes especially on the way crop rotation can be designed. Indeed, a well designed crop rotation can contribute to weed control and a reduction in the use of chemicals (Bagayonko et al., 1992).

Moreover, plant species present in crop rotation influence the soil water holding capacity by reducing soil erosion (Kollas et al., 2015). Diversification of crop along rotations plays an important role in the amount and quality of organic matter entering the soil (Raphael et al., 2016). The mineralization of crop residues can release important quantity of nutrients depending on the used crop, maintaining soil fertility for the following crop and enhance soil microcosm (Askegaard & Eriksen, 2007; Sauvadet et al., 2016).

Soil structure and its granulometric composition are the most important parameters for determining its behavior. Unlike the stable granulometric composition, soil structure reflects the stability of agglomerates and can be strongly altered with the climatic conditions (Abiven et al., 2009) and the soil management and all together change soil porosity, density, invasiveness, and ultimately the availability of water and plant growth. Soil structure regulates water retention and infiltration, gaseous exchanges, soil organic matter and nutrient dynamics, root penetration, and susceptibility to erosion. It constitutes the habitat for a myriad of soil organisms, consequently driving their diversity and regulating their activity (Elliott and Coleman, 1988). As an important feedback, soil structure is actively shaped by these organisms, thus modifying the distribution of water and air in their habitats (Bottinelli et al., 2015; Feeney et al., 2006; Young et al., 2008).

Soil structure depends mainly on the content of organic matter, clay and clay type, inorganic compounds and water. Main interventions that contribute to maintaining or improving the soil structure consist of the addition of organic matter (manure, plant residues, and green fertilization) and crop rotation mainly with legumes (Tisdall & Oades, 1982; Chenuet al., 2000).

Of course, the type of fertilization, quantity, quality and rate of implementation play an important role. Rapidly decomposed organic materials include that exhibiting high glucose content over other elements (Guckert et al., 1975; Skinner et al., 1979). Against soils of different C content, the effect of treatment with green fertilization is higher in soils with low content (Fortun et al., 1996), but not in all cases (Kiem & Kandeler, 1997). Survey results indicate that the effect of green fertilization is more effective in sludge (Browning & Milan, 1944) and in sandy soils (Kiem & Kandeler, 1997).

The effect of green fertilization on the soil structure lasts for few weeks and then returns to its original state. Monnier (1965) associates this periodic rotation of the soil structure with microbial activity. The microbial population that develops after the additional organic substance determines the formation and stabilization of aggregates (Diaz, 1994) and there appears to be a correlation between physical properties and soil biochemistry (Caprielet al., 1990).

Carter (1988) has shown that plant residues cause an increase in macro porous soil, and that there is a high degree of correlation between macro porous and apparent density. The presence of an organic substance in the soil favors the agglomeration phenomenon and the stability of agglomerates. Organic fertilization, as well as crop residues, contributes to the formation of larger diameter weighed aggregates (Cook et al., 1992; Evans et al., 1989).

Including grain legume in crop rotation scenarios has been shown to provide multiple environmental, agricultural and economical benefits. Legumes by their nature symbiotically fix atmospheric N_2 through their association with *Rhizobium* bacteria, leading to lower use of inorganic N (Hardarson et al., 1991; Lopez-Bellido et al., 2006; Turpin et al., 2002). Including legumes at least for one year in the crop rotation scenario will have an influence to soil microbial communities directly (Bunemann et al., 2004) and indirectly through their effects on the quantity, the quality, and the distribution of soil organic matter in upper-soil horizons. Such systems tend to have higher microbial biomass and activities (Moore et al., 2000).

The right period for the incorporation of legumes is dependent on climatic conditions, but mainly depends on the biological stage. According to the literature, green biomass has maximum nitrogen content at the peak during the flowering stage. Research and relevant information on the effect of crops on the soil structure is relatively low. However, it is an important element for the long-term preservation of the structure, in conditions of continuous cultivation. The identification of such plants that are most effective in forming a stable soil structure is a prerequisite for their incorporation into sustainable crop rotation systems (Chan & Heenan, 1996). Various biotic and abiotic factors contribute to the stability of the soil structure. The different plants have different abilities to increase or decrease the processes of the above factors.

Reid & Goss (1981) demonstrated that growing a perennial grass and a clover species increased the stability of agglomerates, maize and tomato reduced the same parameter. In 1988, Angers & Mehuys demonstrated that barley and alfalfa increase the stability of agglomerates in water retention as opposed to maize when compared to fallow controls. An important role in the stability of agglomerates and generally in the structure plays the root system of plants, which can either positively improve the structure or destabilize it by modifying the pH or by modifying the oxidoreducting reactions with the production of organic acids in the root layer and by natural fragmentation of agglomerates from its penetration (Oades, 1984).

The present study was thus conducted to examine the effect of legumes in a crop rotation scenario to the soil structure by incorporating green biomass at the flowering stage of pea.

Materials and Methods

Two field experiments were established in two different soils for three years (2013-2015), e.g. in Trikala (West Thessaly) and in Larisa (East Thessaly), central Greece.

To determine the original soil conditions, samples were collected at two depths (i) 0-20 cm, and (ii) 20-40 cm. For each sample, a pre-treatment was performed before physical and chemical properties were measured, including air drying, pulverization and screening. The latter was carried out using sieves with 2 mm and 0.2 mm diameter circular holes. Physical and chemical properties of the studied soils in the experimental fields before crop establishment are presented in Table 1.

Exact the same proceeding was repeated at the end of the crop rotation experiment during autumn of the 3rd experimental year, and the chemical properties of the soil were re-measured. This sampling was aimed at identifying the biochemical changes resulting from the decomposition of the underground legume biomass that remained in the soil.

A split–plot design 4×3 experimental design was used with 3 replications (blocks) and 8 plots per replication (3×4 = 12 plots). Nitrogen fertilization comprised the main factor (N_0:0, N_1:50, N_2:100 and N_3:150 kg/ha) and three different cultivation practices using legumes comprised the sub-factor (T_0: control, T_1: legume incorporated at the flowering stage, T_2: legume incorporated after seed harvest).

Table 1. Initial physical and chemical properties of the studied soils

	Trikala		Larisa	
Soil Depth	0-20 cm	20-40 cm	0-20 cm	20-40 cm
Sand (%)	60	65	2	2
Silt (%)	18	16	35	32
Clay (%)	22	19	63	66
Characterization (Soil Survey Staff, 1975)	SCL	SC	C	C
pH	7.2	7.6	8.0	8.6
EC (μS cm^{-1})	219	202	458	427
Total N (%)	0.08	0.07	0,09	0.08
Organic Matter (%)	1.3	1.2	1.7	1.3
AvailableP (mg kg^{-1})	16	9	18	12
Available K (mg kg^{-1})	203	177	364	257
Total $CaCO_3$ (%)	4.90	1.60	34.90	30.70

Incorporation of green biomass

Pea biomass incorporation (T1) took place at the stage of flowering (50% flowers; mid April) by plowing and milling. It is found that the maximum total N concentration in legume tissues is observed in the flowering stage (from the beginning to the peak) with nitrogen fixation rates of 2.5 kg N ha^{-1} day^{-1} (Kumar & Goh, 2000).

It has to be mentioned that soil sampling before the crop establishment took place at four points which were signed on the experimental surface, so that the soil samples at the end of the experimentation can be compared in more details. Securing representative samples is the most important factor of objective and impartial research (Fasoulas, 1992), hence the sampling is random.

Soil structure

An easier and rapidly soil classification according to the agglomerate stability, is through the coefficient of instability β, which has been established and shows the stability of agglomerates with a diameter between 2 mm and 4.7 mm in water action (Valmis et al., 1988; Valmis et al., 2005; Argyrokastritis et al., 2002; Dimoyannis et al., 1998).

This coefficient of instability is attributed to the equation:

$$\beta = ((\log(Wa - Ws) - \log(Wi - Ws))/2 \text{ (Dimoyannis, 2009)}$$

The calculation procedure is:

The soil samples must be placed to an air dryer. Then the samples must be sieved with sieves of 2.00-4.75 mm diameter and two subsamples of a specific quantity (up to 10 g) must be weighed in two capsules. One of them must be placed in the oven for 24 hours at 105°C and calculate the soil moisture (Wa). Then the soil sample of the other capsule is immersed in water in a sieve (0.25 mm mesh aperture) for 3 min (wetting) and then subjected to wet screening for 4 min. The wet sieving is done in a special electrically driven mechanism that moves the two sieves vertically at a rate of 72 strokes per minute. The obtained material is weighed (Wi) after having been dispersed with sodium hexafluoride for 10 min (so that all the clay leaves and only the sand fraction is left ≥ 0.25 mm) and then dried in an oven at 105°C for 24 hours (Ws).

The instability index β changes from 0 to 1. With increasing values of β, the instability of aggregates of soil aggregates increases and vice versa, with maximum 1 corresponding to a totally unstable terrestrial structure, and a minimum value of 0, in absolute stable.

Results and Discussion

In Figure 1 are illustrated, the effect of crop rotation on legume (a) and green fertilization by incorporating legume (pea) (b) before the establishment of the spring crops, the stability of the soil structure as reflected by the instability index β (Dimoyannis et al., 1998, Valmis et al., 2005; Dimoyannis, 2009). It is obvious that in the sandy soil of Trikala (Figure 1; Table 2), both green and pea rotation have had a significant effect on the improvement of the soil structure resulting from the decrease in the β ($P \leq 0.05$) instability index compared to the control. In particular, and as shown in Figure 1, the soil structure improves mainly in summer periods, while the rainy period does not show any significant differences in the instability index. The results of the seasonal territorial variation of this research are also in agreement with the literature (Xue-Ming, 1998; Lehrsch & Jolley, 1992). The decrease in the value of the β-index was approximately the same for both treatments of the legume, so that there was no difference between these two treatments (Figure 1; Table 2).

On the other hand, in the heavy clayey soil of Larissa

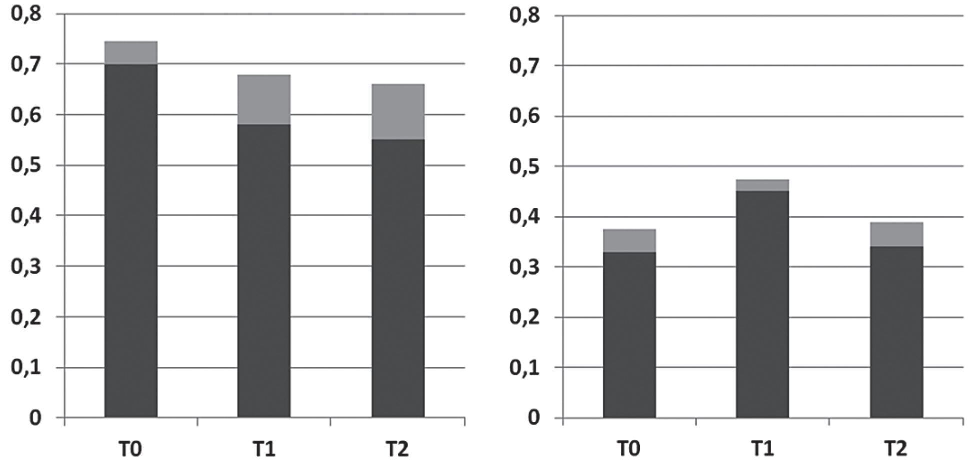

Fig. 1. Indicator of instability of the soil structure (β – y axis) for the three treatments (T_0, T_1, T_2) of the legume (pea) on the sandy terrain of Trikala (left) and the heavy clay soil of Larissa (right). [Average measures for the five samplings. At the top of the columns, the standard deviations per treatment are shown. Treatments: T_1 = green peas incorporation, T_2 = crop rotation with legume fruit, T_0 = control, no legumes]

Table 2. Instability index β of the soil structure for the three treatments (Treatments: T_1 = green peas incorporation, T_2 = crop rotation with legume fruit, T_0 = control, no legumes), on sandy and loamy soil ($0 \leq \beta \leq 1$)

	Trikala				Larisa			
date	T_1	T_2	T_0	LSD[a]	T_1	T_2	T_0	LSD
11/13	0.661	0.591	0.694	0.028*	0.351	0.321	0.354	ns[b]
6/14	0.430	0.321	0.502	0.780*	0.302	0.231	0.222	0.620*
12/14	0.682	0.612	0.701	0.031*	0.411	0.360	0.371	0.253*
7/15	0.441	0.410	0.511	0.079*	0.321	0.222	0.201	0.473*
12/15	0.662	0.601	0.713	0.491*	0.421	0.357	0.312	0.300*
Mean	0.575	0.507	0.624	0.064*	0.361	0.298	0.292	0.690*

*LSD[a]: least significant deference, $P < 0.05$ (*), ns[b]: no significant

(clay = 60%), the instability index β receives much lower values compared to the sandy terrain of Trikala, reflecting the much more stable structure of this territory. However, the results do not show a significant improvement of the (already existing) strong soil structure with rotation and green fertilization, as shown in Figure 1 (right) and Table 2. On the contrary, there is some tendency to increase the β-factor in the case of integration with the control and the treatment of pea harvest (T_2), which was not expected and certainly cannot be interpreted at least without additional experimental data.

The destabilization of the soil structure in the pea crops may be due to the influence of biotic factors or increased soil treatment, as both biotic and abiotic processes are involved in the formation of the soil structure, with the plants altering it by influencing the formation and its stabilization (Harris et al., 1966), with different properties for each plant and their different expression in each soil type. These properties include the ability of plants to produce stabilizing materials in their rhizosphere (Reid & Goss, 1981), but also the different development of underground root system (Tisdall & Oades, 1979), which can destabilize the soil structure by modifying the pH (Oades, 1984), and increasing the production of organic acids in the rhizosphere (Reid et al., 1982), or even by natural fragmentation of the aggregates through the penetration of the root system (Caron et al., 1992). On the other hand, the positive effect of additional organic matter supply from legumes on the stability of the soil structure described in the case of sandy soil has also been recorded in heavy soils with the positive results being short-lived and receding soon (Martin et al., 1955), permitting the predominance of root growth (Forster, 1990), with ultimate expression of relaxation of the soil structure.

Conclusions

The findings shown that rotation cultivating systems with pea can improve soil structure resulting from the decrease in the β instability index. This improve is higher, especially in sandy soils and mainly in summer periods.

The decrease in the value of the β-index was approximately the same for both treatments of pea, reinforcing the conclusion that legumes are deemed necessary in a rotation cultivation scenario.

Improving the soil structure will also lead to higher yields to the following crop. Moreover due to its nature of nitrogen fixation from the atmosphere and the increase of the soil organic C in whole soil, such rotation systems require less fertilizer than mono-crop systems

Therefore, a general conclusion could be that pea in a rotation system seems to be, in these conditions, a suitable crop which leads to the improvement of soil structure and its physicochemical properties and should be seriously taken into consideration for the proposals of the common agricultural policy that should aim to the environmental protection.

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