Available online at www.sciencedirect.com

ScienceDirect

Agriculture and Agricultural Science Procedia 4 (2015) 195 – 200

Agriculture and Agricultural Science Procedia

IRLA2014. The Effects of Irrigation and Drainage on Rural and Urban Landscapes, Patras, Greece

Seasonal flooding and rice cultivation effects on the pore size distribution of a SiL soil

Sofia Kostopoulou[a,*], Chrysa Kallitsari[a], Vassilis Aschonitis[b]

[a]*Laboratory of Soil Science, Faculty of Agriculture, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece*
[b]*Department of Life Sciences and Biotechnology, University of Ferrara, V. Luigi Borsari 46 44121 Ferrara, Italy*

Abstract

In this work we evaluated the effects of a) rice cultivation under flooding conditions and b) seasonal flooding (May-October) without cultivation, on the pore size distribution of a SiL soil. Soil cores were collected from two different depth intervals (0-15 cm and 15-30 cm). After two years under flooding conditions, textural porosity increased at the expense of structural porosity. A percentage of drainage pores collapsed to storage pores; however, this time period was inadequate to bring about changes in the microporosity of the SiL soil. In the depth interval 15-30 cm, the rice root development reduced the effects of flooding on soil porosity.

Peer-review under responsibility of Data Research and Consulting

Keywords: Flooding; porosity; rice

1. Introduction

One of the most cultivated plants worldwide is rice, a crop with high water requirements. Greece is one of the most important rice producers in the European Union. In northern Greece, the rice fields cover areas of 120-195 km^2 within the Deltas of Haliacmon, Axios and Gallikos rivers. Rice cultivation is installed mainly on poorly draining heavy soils such as C, SiC, SiL and SiCL and flooding is the most common irrigation practice (MED-Rice, 2003).

Soil total porosity is distinguished between textural (intra-aggregate) and structural (inter-aggregate) porosity. Structural porosity corresponds to pores >9 μm diameter and consists mainly of medium-and macro-pores which contribute to the flow and redistribution of water in the soil (Brutsaert, 1967; Leij et al., 2002). Under compression,

[*] Corresponding author. Tel: +30 2310 998737 ; fax: +30 2310 998728. Email address: skostop@agro.auth.gr

2210-7843
Peer-review under responsibility of Data Research and Consulting
doi:10.1016/j.aaspro.2015.03.023

as it happens for example under rice cultivation, the pores of the structure are eliminated first, and to a much greater extent than the pores of the texture (Dexter, 1988). Aschonitis et al. (2012) observed that along the soil profile of SiC rice fields of N. Greece, total porosity declined at the expense of the structural porosity and part of the structural pores collapsed to textural pores. The more intense changes were observed in the top soil.

Rice cultivation has serious impacts on the total porosity and the pore size distribution of the soil. During the growing period of rice where flooding conditions prevail, clay swells and is dispersed. The intensity of this phenomenon depends on the texture and structure of the soil, the height of the water and the duration of flooding (Kirchhof and So, 2005). With the action of water, small structural units and primary particles are released from the unstable larger aggregates and migrate with drainage to deeper layers of the soil. There, they are deposited on the walls of the pores and reduce their diameter and reduce the effective infiltration rate of soil (Guidi et al., 1988; Cameira et al., 2003; Sacco et al., 2012). Also, large pores (>30 μm), formed by tillage of the soil after the rice harvest, tend to collapse during subsequent rainfall as the rice fields structure is unstable (Cass et al., 1994). After flooding, a reduction of over 50% of the volume of draining pores (larger than 50 μm) was observed at a depth of 5 cm (Guidi et al., 1988). The lack of drainage pores was found to increase with increasing percentage of clay and duration of flooding (Ringrose-Voase et al., 2000). In a rice-soya-bean rotation system, air-filled porosity (pores >30 μm) declined with depth in the soil and with duration of cropping (Cass et al., 1994).

In this study, we evaluated the effects of a) rice cultivation under flooded conditions and b) seasonal flooding (May–October) without cultivation, on the pore size distribution of a SiL soil. As the main volume of rice roots is found at a depth of 15-20 cm (Papakosta, 2001) and in order to investigate the root development effect on soil porosity, we collected soil cores from two different depth intervals: the topsoil (0-15 cm) and the root-depth (15-30 cm).

2. Materials and Methods

2.1. Study area

The experiment was conducted in lysimeters with a surface area of 4 m^2 each (2×2 m), located at the farm of the University of Thessaloniki. The soil in the lysimeters was uncultivated for more than 10 years. In the spring of 2008, surface vegetation was removed and the upper 25cm of the soil in the lysimeters was disturbed with a mattock and then shattered and leveled with a rake to have a similar seedbed as that achieved in the rice fields by tillage and land leveling. Seasonal flooding conditions (May to October) were established in the lysimeters for two consecutive years (2008, 2009). Certain physicochemical characteristics of the soil in the lysimeters are presented in Table 1.

2.2. Experimental design and data analysis

In November 2009, soil cores of 4 cm height and 5.5 cm in diameter were taken in three replications, from two depth intervals (0-15 and 15-30 cm) from lysimeters a) cultivated with rice under flooding (***rice cultivation – R***) and b) under flooding but without rice cultivation (***flooding – F***). Samples taken in 2008, before the establishment of flooding conditions and rice cultivation, were used as control samples (***control – C***).

The soil cores were wetted by suction to saturation and then equilibrated at successive suctions of 0, 10, 30, 60, 100, 200, 300, 450, 600, 1000 and 1500 kPa (Dane and Hopmans, 2002). The soil water retention curve was designed by the measured pairs (h_j, θ_j). Total porosity was considered equal to the saturated water content (θ_s), with the assumption that the soil water is retained entirely in the pores.

For the determination of the pore size distribution (PSD) we used the measured pairs (h_j, θ_j). Under the assumption that the pores are cylindrical in shape, the equivalent diameter (D) of pores that hold water at a given pressure head (h) was calculated by the following relationship, which arises from the equation of Laplace: $D\ (\mu m) = 298/h\ (kPa)$.

The volume of pores ($cm^3\ cm^{-3}$) of a size class with a diameter between D_{j-1} and D_j was calculated by the difference ($\theta_{j-1} - \theta_j$).

The statistical analysis of the data was performed by one way analysis of variance (ANOVA), at a significance level of α = 0.05. The LSD test was used for the comparison of averages.

Table 1. Physicochemical characteristics† of the soil.

Depth	Sand	Silt	Clay	pH	EC	$CaCO_3$	C	ESP	SAR
cm	%	%	%		mS cm^{-1}	%	%	%	
0-15	17.46	63.45	19.09	7.9	788.5	6.60	1.94	1.13	0.75
15-30	18.85	63.00	18.15	7.9	659.0	6.38	1.22	1.12	0.90

†Determined according to the SSSA Methods of Soil Analysis

3. Results and Discussion

The cumulative curves of PSD for the three treatments (control, flooding, rice cultivation) in the two depth intervals are given in Figs. 1 and 2 respectively. From these figures it can be seen that the shape of the curves changes depending on the treatment and the soil depth.

At the topsoil (0-15 cm), both flooding and rice cultivation altered the PSD in relation to the control, increasing the participation of smaller pores in total porosity. The structural pores (>9 μm) represent over 50% of the total porosity in the control while in the other two treatments their percentage does not exceed 35% (Fig. 1). Richard et al. (2001) observed an increase in textural porosity in silty soils as the result of the collapse of structural pores under wet conditions. If we take into account that total porosity did not differ among treatments (Table 2), it can be argued that the structural pores lost during flooding and rice cultivation are transitioning to textural ones.

At the root-depth (15-30 cm), there is a change in the shape of the PSD curve towards finer pores that is more pronounced under flooding. The structural pores represent 42%, 37% and 28% of the total porosity in the control, under rice cultivation and under flooding, respectively (Fig. 2). The above are consistent with the work of Kallitsari (2014) who showed that the root system of the plant protects the soils of rice fields from the degradation of the porous space.

Total porosity can be divided in three major pore-size classes: the drainage pores with equivalent diameter >30 μm which contribute to the water flow, the storage pores with equivalent diameter 30-0.2 μm which contribute to the redistribution of the water available to the plants and the residual pores with equivalent diameter <0.2 μm, responsible for the immobilization of water in the soil matrix. Total porosity (m^3 m^{-3}), as well as drainage, storage and residual pores expressed as a percentage of the total porosity, are presented in Table 2.

In each treatment, no significant changes were found with depth either in total porosity or in any of the three pore-size classes. In addition, no significant changes in total porosity were observed among treatments, for the two depth intervals (Table 2). These findings are at odds with the findings of other authors who reported that the reduction in total porosity is typical of flooding (Guidi et al., 1988; Rahman et al., 2008). The short time (two years) of rice cultivation and seasonal flooding was probably inadequate to bring about significant changes in soil total porosity or to reveal changes with depth in soil total porosity (Kallitsari, 2014).

However, seasonal flooding and rice cultivation significantly modified the contribution of drainage and storage pores to total porosity, in relation to the control, affecting in this way the flow and redistribution of water within the soil mass. More specifically, in the topsoil the percentage of drainage pores decreased in the order: control > rice cultivation > seasonal flooding (Table 2). In the topsoil, macroporosity reduction under flooding conditions is widely reported (Guidi et al., 1988; Ringrose-Voase et al., 2000; Aschonitis et al., 2012; Sacco et al., 2012). In the root-depth, seasonal flooding significantly decreased drainage pores in relation to the other two treatments. In the root-depth, no difference was found between the control and rice cultivation. The development of the root system of the plant in this depth, contributes to the creation of macro-pores resistant to the destructive action of water as roots are supplying the soil with organic compounds and stabilize the structure (Cameira et al., 2003).

Storage pores differed significantly among all treatments at both depth intervals, with the exception of rice cultivation in relation to the control, at the root-depth. The contribution of storage pores to total porosity was the highest after seasonal flooding, followed by rice cultivation and the control (Table 2). Sacco et al. (2012) observed that flooding water destroyed macroporosity while the volume of pores <30 μm increased.

In the topsoil, the residual pores were not affected by the treatment. At the root-depth the percentage of pores <0.2 μm decreased only after seasonal flooding (Table 2), probably because of the deposition on the walls of the pores and pore infilling with dispersed clay particles that migrate with drainage from the topsoil (Sacco et al., 2012).

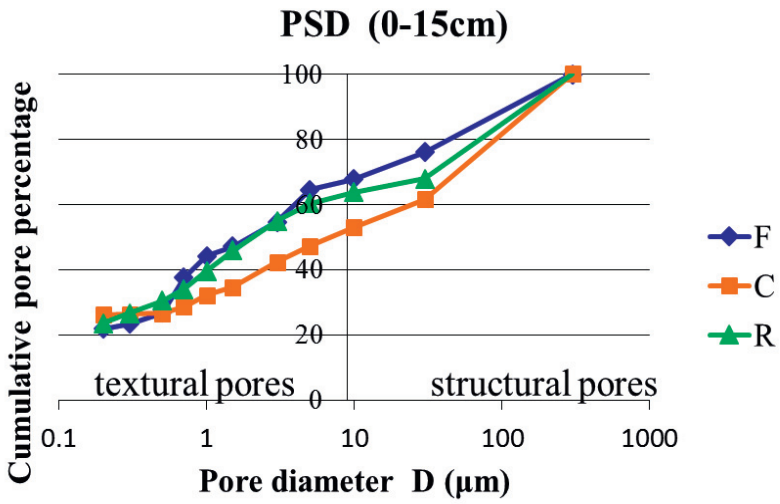

Fig. 1. Cumulative PSD curves for the three treatments (F-flooding, R-rice cultivation, C-control) at the topsoil (0-15 cm).

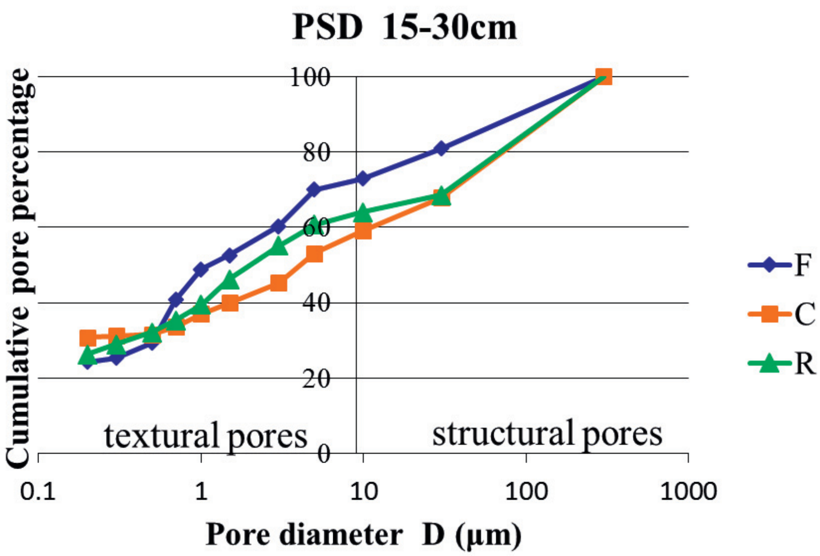

Fig. 2. Cumulative PSD curves for the three treatments (F-flooding, R-rice cultivation, C-control) at the root-depth (15-30 cm).

Table 2. Total soil porosity (m^3m^{-3}) and the distribution (%) of drainage (>30μm), storage (30-0.2μm) and residual (<0.2 μm) pores, for the three treatments at the two depth intervals.

Treatment	Total porosity m^3 m^{-3}	>30 μm %	30 - 0.2 μm %	<0.2 μm %
C (0-15)	0.614 ab†	38.40 c	35.40 a	26.19 ab
C (15-30)	0.573 a	32.16 bc	37.05 a	30.79 b
F (0-15)	0.620 ab	23.94 ab	54.17 c	21.89 a
F (15-30)	0.595 ab	19.04 a	56.70 c	24.26 a
R (0-15)	0.653 b	31.92 bc	44.39 b	23.69 a
R (15-30)	0.613 ab	31.23 bc	42.38 ab	26.39 ab

†Small letters indicate statistically significant differences among treatments at 0.05 confidence level (ANOVA-LSD).

4. Conclusions

Two years under flooding conditions were inadequate to bring about changes in the total porosity of the SiL soil; however, in this time period the pore size distribution changed in a way that adversely affected the flow and redistribution of water in the soil matrix.

Specifically, both rice cultivation and seasonal flooding resulted in an increase of textural porosity at the expense of structural porosity. In the topsoil, structural porosity decreased by the same amount for both treatments but structural pore loss was smaller under rice cultivation in the root-depth.

Flooding conditions affected also the contribution of drainage and storage pores to total porosity. In the topsoil, the percentage of drainage pores decreased and that of storage pores increased in both treatments but the change was more pronounced under seasonal flooding. In the root-depth, air-filled porosity decreased and storage pores increased under seasonal flooding. On the other hand, under rice cultivation the root system development reduced the impact of flooding on the pore size distribution of the soil.

References

Aschonitis, V.G., Kostopoulou, S.K., Antonopoulos, V.Z., 2012. Methodology to assess the effects of rice cultivation under flooded conditions on van Genuchten's model parameters and pore size distribution. Transport in Porous Media 91, 861-876.

Brutsaert, W., 1967. Some methods of calculating unsaturated permeability. Transactions of ASAE 10, 400-404.

Cameira, M.R., Fernando, R.M., Pereira, L.S., 2003. Soil macropore dynamics affected by tillage and irrigation for a silty loam alluvial soil in southern Portugal. Soil & Tillage Research 70, 131-140.

Cass, A., Gusli, S., MacLeod, D.A., 1994. Sustainability of soil structure quality in rice paddy soya-bean cropping systems in South Sulawesi, Indonesia. Soil & Tillage Research 31, 339-352.

Dane, J.H., Hopmans, J.W., 2002. Water retention and storage: Pressure Plate Extractor. In Dane J.H., Topp C. editors. Methods of soil analysis. Part 4. Madison, WI., p. 688–690.

Dexter, A.R., 1988. Advances in characterization of soil structure. Soil & Tillage Research 11, 199-238.

Guidi, G., Pini, R., Poggio, G., 1988. Porosity in a puddled rice soil as measured with mercury-intrusion porosimetry. Soil Science 145, 455-460.

Kallitsari, C., 2014. The change of properties of a silty soil after flooding and rice cultivation. MSc Thesis. Aristotle University of Thessaloniki, School of Agriculture, Forestry and Physical Environment.

Kirchhof, G., So. H.B., 2005. Soil puddling for rice production under glasshouse conditions- its quantification and effect on soil physical properties. Australian Journal of Soil Research 43, 617-622.

Leij, F.J., Ghezzehei, T.A., Or, D., 2002. Modelling the dynamics of the soil pore-size distribution. Soil & Tillage Research 64, 61-78.

MED-Rice, 2003. Guidance Document for Environmental Risk Assessments of Active Substances used on Rice in the EU for Annex I Inclusion. EU Doc. Ref. SANCO/1090/2000-Rev.1, Brussels; June 2003, 108 pp.

Papakosta, D., 2001. Notes on Specific Agriculture I – Cereals, Leguminous, Grasses. Aristotle University of Thessaloniki Publications, p.104-125. (in Greek)
Rahman, M.H., Okubo, A., Sugiyama, S., Mayland, H.F., 2008. Physical, chemical and microbiological properties of an Andisol as related to land use and tillage practice. Soil & Tillage Research 101, 10-19.
Richard, G., Cousin, I., Sillon, J.F., Bruand, A., Guerif, J., 2001. Effect of compaction on the porosity of a silty soil: influence on unsaturated hydraulic properties. European Journal of Soil Science 52, 49-58.
Ringrose-Voase, A.J., Kirby, J.M., Djoyowasito, G., Sanidad, W.B., Serrano, C., Lando, T.M., 2000. Changes to the physical properties of soil puddled for rice during drying. Soil & Tillage Research 56, 83-104.
Sacco, D., Cremon, C., Zavattaro, L., Grignani, C., 2012. Seasonal variation of soil physical properties under different water managements in irrigated rice. Soil & Tillage Research 118, 22-31.