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Investigating long-term effects of subsurface drainage on soil structure in paddy fields

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A B S T R A C T

Subsurface drainage systems provide suitable conditions for annual cropping and crop diversification in northern Iran's paddy fields. Such structural and managerial changes affect soil structure through influencing saturated hydraulic conductivity and effective porosity of the soil. The aim of this research was to investigate the long-term effects of subsurface drainage systems ($D_{0.90}L_{30}$: drainage system with 0.90 m depth and 30 m spacing, $D_{0.65}L_{30}$: drainage system with 0.65 m depth and 30 m spacing and $D_{0.65}L_{15}$: drainage system with 0.65 m depth and 15 m spacing) on the soil saturated hydraulic conductivity and drainable porosity. Water table and drain discharge were measured daily during different growing seasons (2011–2015) following installation of the subsurface drainage systems in the paddy fields of Sari Agricultural Sciences and Natural Resources University. The saturated hydraulic conductivity was calculated using Hooghoudt and Glover-Dumm equations and the drainable porosity was calculated with Taylor's method. Computed hydraulic conductivities by the Hooghoudt and Glover-Dumm equations were in the range of 0.002 to 1.95 m day^{-1} and 0.003 to 2.5 m day^{-1}, respectively, that highest value was related to $D_{0.65}L_{15}$ and lowest value was related to $D_{0.90}L_{30}$. So, the shallow drainage systems were more effective in improving the soil hydraulic condition compared with the deep ones. The drainable porosity in the $D_{0.90}L_{30}$, $D_{0.65}L_{30}$ and $D_{0.65}L_{15}$ systems ranged from 0.002 to 0.314 $m^3\,m^{-3}$, 0.003 to 0.13 $m^3\,m^{-3}$ and 0.004 to 0.126 $m^3\,m^{-3}$, respectively. In conclusion, the installation of subsurface drainage especially at the shallower depth will improve paddy soil structure during time.

1. Introduction

As one of the most important physical and dynamic properties of soil, soil structure forms due to the action of forces that push soil particles together. The soil structure affects plant growth and yield production by influencing carbon and other nutrients' cycle, uptake, water retention and movement, aeration, soil thermal conductivity, mechanical resistance and resistance against erosion (Diaz-Zorita et al., 2002). Physical and chemical characteristics of soil and ecological and human factors have a direct impact on the soil structure over long time. Soil structure response to these factors has been investigated by researchers in different ways. Polymers were found to increase soil porosity and infiltration rate of water into soil (Gal et al., 1992). Also, applying different organic amendments such as green manures and gypsum has reported to improve sodic soil structure (Udayasoorian et al., 2009) as well as soil hydraulic conductivity and soil available moisture. Moreover, change in land-use and crop diversification causes soil structure variation by changing soil characteristics (Zolfaghari et al., 2015). Celik (2005) reported that converting pasture into agricultural land significantly reduced the soil organic matter. Additionally, it is reported that deforestation and subsequent tillage practices resulted in a 20% increase in bulk density and a 50% decrease in soil organic matters (Hajabbasi et al., 1997).

In paddy fields, soil structure is also subject to drying and wetting patterns, clay content, crop diversification, puddling and other farming and managing factors. In a study of Levy et al. (2005), it was shown that soil wetting and texture affected aggregate stability. Variation in moisture condition of paddy soils has profound effect on organic materials, nutrient dynamics, carbon protection and soil fertility (Witt and Haefele, 2005). Puddling of paddy fields can destroy the soil surface layer to a specific depth, resulting in changes of soil physical, chemical and biological properties. Sharma and De Datta (1985) reported that bulk density of the surface layer (0–10 cm) in a lowland clay and clay loam soil declined as a result of puddling, but as particles settled, the

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Table 1
Monthly mean temperature (°C) in the experimental site during the study period.

Year	Month											
	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
2011	–	–	–	–	–	–	28.9	27.3	24.0	18.3	9.7	7.3
2012	7.6	5.4	8.9	18.0	23.5	25.6	26.8	28.5	24.3	21.2	15.3	9.7
2013	9.2	9.3	12.9	15.5	21.3	24.9	26.8	26.1	25.5	18.9	15.1	8.1
2014	8.2	6.6	11.6	17.1	23.4	25.7	27.7	28.6	26.2	18.5	12.1	9.3
2015	8.1	9.4	10.4	15.8	22.2	26.7	27.4	27.7	25.0	20.2	12.3	8.7
2016	9.3	9.3	12.0	16.0	–	–	–	–	–	–	–	–

bulk density of the submerged soil increased with time. In another study, a high percolation rate was reported at the beginning of the puddling with decreasing trend over time due to clogging of soil pores as a result of soil swelling, clay migration, root penetration, or microbial activity (Painuli et al., 1988). Also, increase in puddling intensity may finally decrease hydraulic conductivity of the soil layer.

A major characteristic of the soil in northern Iran's paddy fields is heavy texture (Darzi-Naftchali et al., 2014) with inadequate natural drainage causing long-time waterlogging and ponding which may increase soil salinity and sodicity resulting in negative influence on paddy field productivity and rice production (Masanneh-Ceesay, 2004).

In addition to water table control, proper subsurface drainage prevents soil salinization and facilitates salts leaching from the root zone of the soil profile (Ritzema et al., 2008). Shiratori et al. (2007) showed obvious change in soil characteristics due to the installation of a subsurface drainage system in a heavy paddy soil. Improved soil condition may alter the flow condition in the soil profile. On the other hand, the quantity and quality of drainage water is a function of drain depth and spacing (Wahba and Christen, 2006). In a field study, it was shown that by increasing the drain spacing, the electrical conductivity and volume of drainage water decreased (Jafari-Talukolaee et al., 2015). By investigating the effects of deep and shallow drainage systems on the quantity of drainage water in Southern Australian irrigated lands, Christen and Skehan (2001) showed that decreased drain depth and spacing resulted in lower amount of drainage water. Jafari-Talukolaee et al. (2016) demonstrated variable responses for different subsurface drainage systems in a heavy textured soils of paddy fields in the north of Iran. The study revealed that shallow drains were more effective than deeper ones in controlling the water table depth during three first years after the introduction of subsurface drainage while the reverse trend was observed in the fourth year.

As discussed above, the response of soil hydraulic characteristics to various practices have been investigated in previous studies. However, no information is available on the response of soil porosity and hydraulic conductivity to subsurface drainage systems with different depth and spacing. These parameters which affect soil structure and are used in drainage equations and simulation models, are subject to variation in space and time. On the other hand, because of their variability, it is better to determine them from large-scale experiments (e.g., from the functioning of existing drainage systems or from drainage experimental fields), rather than from small-scale experiments (Ritzema, 1994). Therefore, the aim of this study was to investigate the variation of saturated hydraulic conductivity and drainable porosity in paddy fields with different subsurface drainage systems under rice- canola cropping system.

2. Materials and methods

2.1. Study field

This research was carried out in a 3 ha of consolidated paddy fields at the Sari Agricultural Sciences and Natural Resources University (SANRU), located in Mazandaran province, north of Iran, during 10 successive growing seasons (July 2011 to April 2016) including five rice growing seasons and five canola growing seasons. Based on the long-term meteorological data, mean temperature and mean annual rainfall of the study site are 17.6 °C and 643 mm, respectively. Table 1 shows mean monthly temperature of the experimental site during the study period. The soil at the site is silty clay to a depth of 150 cm and is clay in the 150–300 cm layer. Textural class and other soil characteristics at the experimental site are specified in Table 2.

The paddy fields were consolidated in 2003, and the plots were regulated as rectangular shape with the same area (0.3 ha, 100 m long and 30 m wide) (Darzi-Naftchali et al., 2013). Three types of subsurface drainage systems were installed in these fields in July 2011 at 0.65 and 0.90 m depths and variably spaced at 15 and 30 m. Overall, seven lines of subsurface drains have been installed to be fully independent of one another including three lines with 0.90 m depth and 30 m spacing ($D_{0.90}L_{30}$), two lines with 0.65 m depth and 15 m spacing ($D_{0.65}L_{15}$) and two lines with 0.65 m depth and 30 m spacing ($D_{0.65}L_{30}$). PVC corrugated pipes with an outside diameter of 100 mm and 100 m long were used as lateral drains with a slope of 0.2%. Mineral materials (sand and graded silt) were used as envelope materials around the pipe. The drainage water of all laterals is drained into an open channel. Further details about the experimental site can be found in Darzi-Naftchali et al. (2013) and Jafari-Talukolaee et al. (2016).

2.2. Measurements

From July 2011 to April 2016, during 10 successive growing seasons, rice and canola were cultivated in the study area. For prevention of water and nutrient losses during rice growing seasons, the outlet of drain pipes was held closed except during the midseason and end-season drainage periods. Midseason drainage was adopted 25 days after rice transplanting in the three first rice growing seasons while alternate wetting and drying (AWD) was practiced in fourth and fifth growing seasons. Under AWD, two periods of drainage were practiced during the vegetative growth stage. The duration of the drainage periods depended on the formation of cracks on the soil surface (Darzi-Naftchali et al., 2017). In order to facilitate the use of farm machinery, the fields were drained several days before harvest. During the canola growing seasons,

Table 2
Textural class and some characteristics of the soil of the experimental site.

Soil depth (cm)	Clay (%)	Silt (%)	Sand (%)	Soil texture	Bulk density ($g\,cm^{-3}$)	pH	Total nitrogen (%)	Organic carbon (%)
0 − 30	48.5	44.5	7.0	Silty clay	1.40	8.00	0.10	1.47
30–60	55.5	42.0	2.5	Silty clay	1.34	8.10	0.08	1.51
60–90	46.5	45.5	8.0	Silty clay	1.37	7.95	0.08	1.47