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Influence of subsurface drainage on the productivity of poorly drained paddy fields

Abdullah Darzi-Naftchali*, Ali Shahnazari

Water Engineering Department, Sari Agricultural Sciences and Natural Resources University, Sari, Iran

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ABSTRACT

Because of the relatively flat topography of Northern Iran consolidated paddy fields and inadequate natural drainage facilities, these lands are usually confronted with waterlogging due to periodic excess of water from rainfall during the wet months. The productivity of these areas could be greatly increased if their drainage problems were solved by subsurface drainage. Subsurface drainage may also facilitate the mid-season drainage (MSD), one of the water management methods during the rice growing season. A drainage pilot consisting of surface and subsurface drainage with different drain depths and spacings was designed at Sari Agricultural Sciences and Natural Resources University, Iran, to explore the effect of different drainage systems on the productivity of paddy fields. Rice cultivation was carried out during two cropping seasons, 2011 and 2012. In 2011, after rice harvest, canola seed was cultivated in the subsurface drained area. For MSD, the fields were drained 25 days after rice transplanting and remained drained for 7 days. Randomized complete block design was used to find the effect of drainage on crops. The implementation of MSD through subsurface drainage, significantly increased yield, yield components and growth parameters of rice. Rice yield of the subsurface drained area was approximately 1.22–1.66 and 1.32–1.7 times higher than that of the surface drained area in 2011 and 2012, respectively. Subsurface drainage provided better condition for canola cropping while, because of waterlogging, it was not possible under surface drainage. An economic analysis showed that the cost of installing subsurface drainage systems was readily justified by annual increased rice and canola yields. Based on the results, the introduction of the subsurface drainage resulted in an increase in both crop yield and cropping intensity in the study area.

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1. Introduction

The world's population is projected to grow to more than 9100 million in 2050 (Ritzema, 2009). Well over half of the developing world's population – 3.1 billion people, or 45 percent of all humanity – live in rural areas. Of them, roughly 2.5 billion derive their livelihoods from agriculture (FAO, 2012). To feed this growing population and banish hunger from the world, food and feed production will need to be increased. Rice is one of the leading food crops of nearly half of the world's population (IRRI, 2003). The number of consumers is expected to increase in future because of increasing population, rapid urbanization and change in diets (Fonteh et al., 2013). Based on Ray et al. (2013), global production of rice would increase by 42%, which is far below what is needed to meet projected demand in 2050. Globally, the total rice cultivated area is 153.65 million ha (FAO, 2012), most of which is grown in Asia, which represents 90% of the global rice growing area (Antonopoulos, 2010; Singh et al., 2001).

Following wheat, rice is the second principal dietary item of Iranian people. According to FAO (2012), total area of Iran's paddy fields is 564 thousand hectares, more than 75% of which located in two Northern provinces (Mazandaran and Guilan). Total annual rice production of the country was 2253 and 2288 thousand tons in 2009 and 2010, respectively. At present, the total national production does not satisfy total rice requirement of the country. The deficit is met through importation from other countries. In 1999, 2007, 2008, and 2009, respectively, rice imports to the country were 852, 949, 1138, and 802 thousand tons (FAO, 2012).

Paddy field plots are enclosed by bunds. The traditional plots were irregular in shape and their area was small. To improve farming efficiency and increase rice productivity along with to reduce poverty and to create employment, particularly in rural areas, the Government of Iran gave priority to conduct land consolidation projects in the Northern Iran paddy fields during the past two

* Corresponding author. Tel.: +98 1513822892; fax: +98 1513822892.
E-mail address: abdullahdarzi@yahoo.com (A. Darzi-Naftchali).

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decades. A standard paddy plot with the size of 30 m × 100 m was implemented, and fields were improved by separating water supply and drainage functions. Because of the relatively flat topography of the consolidated paddy plots and inadequate natural drainage facilities, these lands are usually confronted with the problems of too much water and inundation due to periodic excess of water from rainfall during the wet months. These problems result in unsuitable condition for winter cropping due to the inability of surface drains to remove the excess water in due time.

On the other hand, the Northern Iran paddy fields, with their high rainfall and moderate temperatures, offer excellent opportunities for year-round crop production. Because of the limited soil and water resources for further expansion of agricultural land and to achieve self-sufficiency in food grain production; increased productivity, profitability and sustainability of these fields are essential to reduce poverty in rural areas and thus important for achieving sustainable development goals. Per capita arable land availability in Iran is 0.15–0.3 ha (FAO, 2012) which is declining due to population increase. Therefore, the increased production is primarily due to higher productivity rather than increased area under cultivation. The productivity of these areas could be greatly increased if their drainage problems were solved by subsurface drainage. This enables crop diversification through quick control of the soil water in the root zone required for the crops other than rice.

In spite of the importance of internal soil drainage for upland crops, wetland rice culture requires water control for which adequate drainage provisions are essential to remove excess water. Rice fields are irrigated simultaneously and continuously during the irrigation season, so there is no need to drain the irrigated water except at the time of midseason and harvest time. Mid-season drainage (MSD) was widely adopted in rice cultivation where irrigation/drainage system was well managed (Liu et al., 2013). This practice supplies oxygen to soil (Stoop et al., 2002; Rahman et al., 2013) and temporally keeps soil conditions oxidative (Shiratori et al., 2007) and prevents accumulation of potentially toxic substances to root growth (Zou et al., 2007; Bouman et al., 2007) and, thus, will be effective in enhancing root activity (Furukawa et al., 2008; Osaki et al., 2001) and decrease in CH_4 production potential in the soil (Shiratori et al., 2007; Bouman et al., 2007). Drainage problems at harvest might have important financial consequences for farmers, both because of increased production costs and of a reduction in rice quantity and quality (Vandersypen et al., 2007). During the harvesting period the surface soil layer must be drained approximately 2 weeks before harvest (Inoue and Tokunaga, 1995), so that there will be sufficient soil bearing capacity for effective machinery operations (Ogino and Ota, 2007).

Despite the positive consequences of drainage, the high initial investment costs are a major obstacle for large-scale implementation of subsurface drainage systems at Northern Iran paddy fields. In this area, the majority of farmers are smallholders, owning less than 1 ha of paddy field and harvesting one crop a year, hence they are too poor to pay the cost of drainage. Recently, the Government of Iran has become interested in dealing with waterlogging and to increase paddy fields productivity by introducing new subsurface drainage systems. Sari Agricultural Sciences and Natural Resources University (SANRU) as a pioneer center in this matter have implemented a subsurface drainage pilot with different drain depths and spacings. Such a study at the pilot scale is a first step before moving to the farm scale with a view to identifying farmers' socio-economic constraints to improve their cropping systems. In this pilot, MSD, a major water management practice in rice growing season, was conducted through surface and subsurface drainage systems during two rice crop seasons. The present study was undertaken to quantify the influence of such water management of the rice production system, including canola as a rotation crop. Also, an economic analysis of subsurface drainage installation was presented based on yield increases due to subsurface drainage.

Table 1
Monthly means of average air temperatures and rainfall for rice growing seasons of 2011, 2012 and the long-term average at the experimental site.

Month	Mean temp (°C)			Rainfall (mm)		
	2011	2012	Long term	2011	2012	Long term
May	19.3	22.5	20.2	45.5	2.8	19.9
Jun	25.9	25.2	24.5	23.4	43.7	17.4
Jul	28.9	25.3	26.7	0	30	17.6
Aug	27	26.8	27.1	22.5	22.3	18.9
Sep	23.8	–	24.4	76.5	–	53.9
Oct	17.8	–	20	122.9	–	67.8

2. Materials and methods

The experimental site is located in the coastal plain of Northern Iran at the Sari Agricultural Sciences and Natural Resources University (36.3° N; 53.04° E; 15 m below sea level) in the Mazandaran province. The site is a 4.5 ha consolidated paddy field divided into 12 plots. Weather data were recorded daily in the experimental area and are given in Table 1 (reported as mean monthly data for the 2 years of the study), together with the long-term average of temperature and rainfall. In this part of the province, the long-term average annual rainfall is 616 mm about 70% of which occurs over the October–March period. Long-term annual average temperature is about 17.3 °C. The mean annual pan evaporation is 2500 mm. The soil on the site is silty clay at the upper 200 cm and clay at 200–300 cm depth, which under natural conditions is very poorly drained. Textural class and saturated hydraulic conductivity of the soil of the experimental site are given in Table 2.

Different subsurface drainage systems were installed prior to the design and implementation of this field experiment. Drainage treatments were: three conventional subsurface drainage systems with mineral (sand and graded silt) envelopes including drainage system with drain depth of 0.9 m and drain spacing of 30 m ($D_{0.9}L_{30}$), drain depth of 0.65 m and drain spacing of 30 m ($D_{0.65}L_{30}$), and drain depth of 0.65 m and drain spacing of 15 m ($D_{0.65}L_{15}S$); a conventional subsurface drainage system with drain depth of 0.65 m and drain spacing of 15 m with pre wrapped geotextile material ($D_{0.65}L_{15}F$); a bi-level subsurface drainage system with drain spacing of 15 m and drain depths of 0.65 and 0.9 m as alternate depths (Bilevel), and surface drainage system with drain depth of 1.2 m (Control). The subsurface drains were connected to a surface drainage ditch approximately 1.2 m deep. Detailed description of the drainage systems is presented in Darzi-Naftchali et al. (2013). The layout of the drainage treatments for the experiment is given in Fig. 1.

Rice cultivation was carried out during two cropping seasons: July 21–22 to October 10, 2011 and May 28–29 to August 11,

Table 2
Textural class and saturated hydraulic conductivity (K_s) of the soil of the experimental site.

Soil depth (cm)	Clay (%)	Silt (%)	Sand (%)	Soil texture	K_s (cm/day)
0–30	48.5	44.5	7	Silty clay	25.6
30–60	55.5	42	2.5	Silty clay	8.1
60–90	46.5	45.5	8	Silty clay	20.7
90–120	42.5	51.5	6	Silty clay	16.3
120–150	52	42	6	Silty clay	10.9
150–200	58.5	35.5	6	Clay	8.3
200–300	61	33.5	5.5	Clay	2.5

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