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# Quantifying hydrological effects of crop diversification in Northern Iran paddy fields

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**Abstract**

There are human and animal health concerns related to drainage systems because nutrients, especially nitrogen and phosphorus, can contaminate water supplies. A field study was conducted on consolidated paddy fields of Sari Agricultural Sciences and Natural Resources University, Northern Iran (36.3°N, 53.04°E), to determine the effect of subsurface drain depth and spacing on nitrogen (N) and phosphorous (P) dynamics, the nutrients of most concern in eutrophication of receiving water bodies. During three successive rice -canola-rice growing seasons from July 2011 to August 2012, drainage and leaching losses of TN and TP were measured. TN and TP losses in untrained fields were 267 and 24.6 kg ha-1, respectively, while, such losses ranged from 41-50.6 for TN and 0.98-1.53 for TP, during the study period. The results showed that introduction of subsurface drainage in the study area, in addition to providing better condition for canola cropping and utilization of soil nutrients, considerably decreased nutrient losses.

**Keywords***:* Environment, Nutrients losses, Productivity, Subsurface drainage

## 1. Introduction

The paddy fields of Northern Iran provide the majority of the country rice requirements. However, the contribution of paddy to national economy keeps decreasing. Ponding and waterlogging problems (Darzi et al., 2007) along with low incomes and pressure for land has resulted in large areas of wet zone paddy lands being left fallow or converted to different purposes. Subsurface drainage system was considered as a major solution to improve the productivity of these poorly drained paddy fields (Darzi-Naftchali and Shahnazari, 2014) as part of a land consolidation project. While the benefits to crop production are evident, drainage system design has great influence on the amount of nitrogen lost from a drainage system (Gilliam and Skaggs, 1986). Drainage systems accelerate the leaching of minerals and NO3 from the plow layer of paddy fields (Singh et al., 2002). Therefore, there is a growing concern relative to detrimental impact of nutrient losses on the quality of surface and groundwater bodies. In addition, recent increases in fertilizer costs as a result on energy shortage make it necessary to reduce nutrient loss from the flooded soil systems.

With regard to the use of about 30% of lands for crop production and pasture and 70% of the world's fresh water consumption in agriculture (FAO, 2012), there is no doubt that agriculture should be the core of any discussion related to the management of environment and natural resources to sustain their quality and quantity.. On the other hand, agriculture has a complex relationship with natural resources and quality of ecosystems. Quality of ecosystems and improving economic opportunities are twin elements of world sustainability. Therefore, a better understanding of the relationship between economic development and environmental quality is necessary to adopt environmental friendly policies which ensure sustainable development. According to about 210 thousand ha paddy fields in Mazandaran province, evaluation of different strategies to achieve high levels of yield and increased productivity of paddy fields with minimal negative impacts on the basic natural resources, soil and water, is essential to achieve self-sufficiency in strategic crops. Moreover, due to the increasing pressure of climate change on water resources (Finger, 2012) and regarding that the increased competition for water resources has become a major challenge for food production, communities and environment, use appropriate measures to reduce nutrient losses from paddy fields, besides increasing the efficiency of such nutrients reduces surface and groundwater pollution. Hence, this study was conducted to quantify the environmental consequences of crop diversification in the consolidated paddy fields of Northern Iran.

## 2. Materials and Methods

A drainage pilot was implemented at 4.5 ha consolidated paddy fields of Sari Agricultural Sciences and Natural Resources University ($36.3^0$ N; $53.04^0$ E; 15 m below sea level) located at Mazandaran province, Northern Iran. 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. Mean annual rainfall at the site is 616 mm and pan evaporation is 2500 mm. The mean, minimum, and maximum air temperatures are 17.3, -6, and $38.9^0$C, respectively. In this pilot, different subsurface drainage systems were installed with two drain depths of 0.65 and 0.9 m and two drain spacing of 15 and 30 m. Therefore, subsurface drainage treatments were: three conventional subsurface drainage systems 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 ($D_{0.65}L_{15}$); 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).The drainage water of all laterals is drained into an open channel of 1.2 m depth which also acts as a surface drain for the study paddy plots. Three paddy plots which were only under influence of the surface drain were selected as Control treatment. Detailed description of the drainage pilot was presented in Darzi-Naftchali et al. (2013) and Darzi-Naftchali and Shahnazari, 2014.Layout of drainage treatments and instrument installation was presented in Fig 1.

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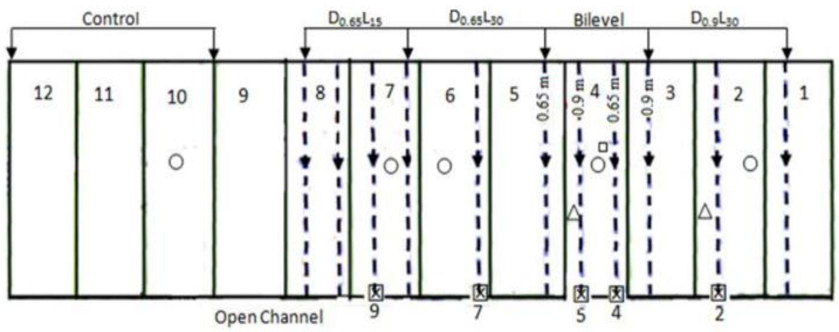


(1 to 12 plot no., ○: location of observation wells, opened end lysimeter for measuring evaporation +deep percolation (E+DP), soil sampling and suction samplers with porous ceramic cups, △: location of closed end lysimeter for measuring evaporation (E),□: location of opened end lysimeter for measuring evapotranspiration (ET), ▬ ➔▬ : subsurface drain lines and ⊠: point of drain flow measurement).

Fig. 1: Layout of drainage systems and instrument installation in the experimental site

Field experiments were carried out during July 2011 to August 2012. In this period, local Tarom rice cultivar was cultivated twice as spring cropping (July 21-22 to October 10, 2011 and May 17-18 to August 10, 2012). After rice harvest, with no till management, 6 kg $ha^{-1}$ of canola seed (Hayola 401 cultivar) with minimum physical purity of 98% and minimum viability of 85%, was cultivated in subsurface-drained plots on November 28, 2011 and was harvested on May 10, 2012. The Control plots were remained fallow during canola cropping season due to waterlogging and pounding in rainy seasons. The record of agricultural activities and fertilization during the study period is summarized in Table 1.

Table 1: The record of agricultural activities and fertilization during three growing seasons of rice-canola-rice

| Date | Agricultural activities and fertilization | Remarks |
|---|---|---|
| | 2011 rice season | |
| July 9 to July 18 | Plowing and puddling | |
| July 19 | Basal fertilization | 140 kg $ha^{-1}$ triple superphosphate |
| July 21 to July 22 | Rice transplanting, Variety: Tarom | |
| July 28 | Fertilization | 90 kg $ha^{-1}$ urea |
| August 15 to August 21 | Midseason drainage | |
| September 21 | Irrigation cessation and endseason drainage | |
| October10 | Harvest | |
| | 2011-2012 canola season | |
| November 28, 2011 | Seeding | |
| March 7, 2012 | Fertilization | 35 kg $ha^{-1}$ urea |
| March 27, 2012 | Fertilization | 35 kg $ha^{-1}$ urea |
| May 10, 2012 | Harvest | |
| | 2012 rice season | |
| May 8 to May 15 | Plowing and puddling | |
| May 17 to May 18 | Rice transplanting, Variety: Tarom | |
| May 25 | Fertilization | 90 kg $ha^{-1}$ urea |
| Jun 12 to Jun 19 | Midseason drainage | |
| July 25 | Irrigation cessation | July 26: endseason drainage |
| August 10 | Harvest | |

In the rice growing seasons, flooding-midseason drainage-reflooding water management was implemented. Besides water management, all agricultural operations were done in accordance with conventional methods used in the region. For midseason drainage (MSD), the fields were drained 25 days after transplanting for 7 days. In the canola season, free drainage was implemented in the period from canola planting date (November 28, 2011) to April 2, 2012. During the drainage periods, drainage effluents were sampled. Also, leachates were collected at a depth of 60 cm for every 15- day intervals during the rice and canola seasons. TN, and TP concentrations of water samples were measured by the standard methods. At the beginning and end of each growing seasons, soil samples were taken from three different layers (0-30, 30-60, and 60-90 cm) to determine TN and TP. The productivity of subsurface drained and conventional paddy fields was compared by determining crop yield.

## 3. Results and Discussion

TN and TP losses through drainage and leaching during the study period are presented in Table 2.The minimum and maximum drainage losses of TP were 0.22 and 0.58 kg $ha^{-1}$ related to $D_{0.9}L_{30}$ and $D_{0.65}L_{15}$,

respectively, reflecting that by reducing the depth and spacing of subsurface drains, P losses increase. Comparison of drainage losses of TP in $D_{0.9}L_{30}$ and $D_{0.65}L_{30}$ treatments and Bilevel and $D_{0.65}L_{15}$ treatments shows that increase in drain depth decreases P losses through drainage. Decrease in drain depth and spacing result in decrease in the distance for lateral flow to the drains which finally may cause increase in P losses. On the other hand, less drain depth can increase the chances of the preferential P flow in soil. During two rice growing seasons, TP losses through surface runoff was 0.27 kg ha$^{-1}$. The bonding capacity of P to any provides suitable condition for P loss through surface runoff. Previous studies reported the average runoff losses of P during a rice planting season 1.43 kg ha$^{-1}$ (Yoon et al., 2006), 1.75 kg ha$^{-1}$ (Guo et al., 2004) and 4.1 kg ha$^{-1}$ (Cho et al., 2000). Lower losses in the present study are due to the short periods of drainage (i.e. midseason and end season drainage periods). Same as drainage losses, leaching losses of P were not significant in subsurface drained areas.

Among different subsurface drainage systems, the highest TP leaching was 1.13 kg ha$^{-1}$ corresponded to the $D_{0.65}L_{30}$ treatment which is the less intensive drainage system in the study area. A high value of TP leaching was observed in the Control (24.33 kg ha$^{-1}$). Notably that such loss was a result of fallow period after 2011 rice season in which soil P was decreased due to frequent rainfall. Moreover, P inflow through precipitation was lost however, this inflow was not significant (about 0.8 kg ha$^{-1}$).Cultivating canola as a living mulch in the subsurface drained area reduced TP leaching through plant uptake.

As it expected, TN losses were considerably higher than TP losses.

The minimum and maximum drainage losses of TN were 6 and 13.5 kg ha$^{-1}$ related to $D_{0.65}L_{30}$ and $D_{0.65}L_{15}$, respectively. During rice growing seasons, surface runoff was a major path for TN losses. Several studies reported N losses by surface runoff during a rice season as: 42- 48 kg ha$^{-1}$ (Takeda et al., 1991), 149.2 kg ha$^{-1}$ (Cho et al., 2000), 15 kg ha$^{-1}$ (Kim and Cho, 1995) and 53.4- 68.3 kg ha$^{-1}$ (Yoon et al., 2006). In the present study, N was measured only in the runoff of midseason and end season drainage periods and possible losses in the other periods were neglected.

In subsurface drained areas, leaching losses of TN ranged 32.5- 44.6 kg ha$^{-1}$, indicating that N leaching may lead to a potential pollution of groundwater. The maximum TN leaching was from the $D_{0.65}L_{30}$, which caused the minimum drainage losses of TN. Comparison of drainage and losses of TN shows that it is possible to properly balance between these losses by the construction of optimum subsurface drainage systems, based on the sensitivity of receiving water. If groundwater is more sensitive than surface water, the subsurface drain spacing can be decreased which reduces the entry of nutrients and chemicals into the groundwater aquifers (Drazi-Naftchai et al., 2013).Where surface water is at risk, the subsurface drain spacing can be increased to diminish nutrient losses to surface water.TN leaching in the Control was 259.8 kg ha$^{-1}$ with major losses occurring during fallow period from 2011 rice harvest to the beginning of 2012 rice season.

To compensate for the loss of nutrient losses from agricultural lands, use of chemical fertilizers is inevitable. Table 3 shows TN and TP losses and their equivalent fertilizer losses during the study period.

During the study period, losses of P fertilizer were not significant in subsurface drained areas while, it was considerable in un drained land.TP losses in the $D_{0.9}L_{30}$, Bilevel, $D_{0.65}L_{30}$, $D_{0.65}L_{15}$, and Control were equivalent to, respectively, about 5.4, 4.8, 7.2, 7.5, and 121 kg triple superphosphate fertilizer, 3.9, 3.4, 5.1, 5.4, and 86.4 % of applied fertilizer (140 kg ha$^{-1}$).Total urea losses in the $D_{0.9}L_{30}$, Bilevel, $D_{0.65}L_{30}$, $D_{0.65}L_{15}$, and Control were, respectively, about 89.1, 96.7, 110, 101.7, and 580.4 kg ha$^{-1}$,35.6, 38.7, 44, 40.7, and 232 % of applied urea (250 kg ha$^{-1}$).

Much nutrient losses in the Control treatment indicate that subsurface drainage is necessary for better utilization of soil nutrients in the study area which is prone to water logging and ponding during rainy seasons.

Table 2: Drainage and leaching losses of TN and TP during the study period

| Treatments | TP losses (kg ha$^{-1}$) | | TN losses (kg ha$^{-1}$) | |
|---|---|---|---|---|
| | Drainage | Leaching | Drainage | Leaching |
| $D_{0.9}L_{30}$ | 0.22 | 0.9 | 8.5 | 32.5 |
| Bilevel | 0.34 | 0.64 | 10.5 | 34 |
| $D_{0.65}L_{30}$ | 0.32 | 1.13 | 6 | 44.6 |
| $D_{0.65}L_{15}$ | 0.58 | 0.95 | 13.5 | 33.3 |
| Control | 0.27 | 24.33 | 7.2 | 259.8 |

Table 3: Total losses of N and P and their equivalent fertilizer losses

| Treatments | Nutrient losses (kg ha-1) | | Fertilizer equivalent (kg.ha-1) | |
|---|---|---|---|---|
| | TP | TN | Triple superphosphate | Urea |
| D0.9L30 | 1.12 | 41 | 5.4 | 89.1 |
| Bilevel | 0.98 | 44.5 | 4.8 | 96.7 |
| D0.65L30 | 1.47 | 50.6 | 7.2 | 110 |
| D0.65L15 | 1.53 | 46.8 | 7.5 | 101.7 |
| Control | 24.6 | 267 | 120.6 | 580.4 |

Besides better utilization of soil nutrients, subsurface drained fields were more productive than conventional fields. The yield of rice and canola for different growing seasons is depicted in Figure 2.Grain yield of subsurface drainage treatments was approximately 1.22-1.66 and 1.32-1.7 times higher than that of Control in 2011 and 2012, respectively. The Bilevel treatment produced the highest grain yield, 66 and 70% greater than that of the Control treatment in 2011 and 2012, respectively. Increase in grain yield due to subsurface drainage has been reported in previous studies (Mathew et al., 2001; Satyanarayana and Boonstra, 2007;Ritzema et al., 2008). The significant increase in crop production can be attributed to the direct effects of the introduction of subsurface drainage. Subsurface drainage effectively controlled the water table and then provided better aeration in the root zone in mid-season period. The minimum and maximum canola yield were 688 and 1129 kg ha$^{-1}$, respectively, related to the $D_{0.9}L_{30}$ and $D_{0.65}L_{15}$ treatments. Better aeration in the $D_{0.65}L_{15}$ provided better condition for canola growth. In the canola season, the $D_{0.65}L_{15}$ was the most effective drainage system to control the depth of the water table followed by the $D_{0.65}L_{30}$, Bilevel, and $D_{0.9}L_{30}$ treatments (Darzi-Naftchali et al., 2013).

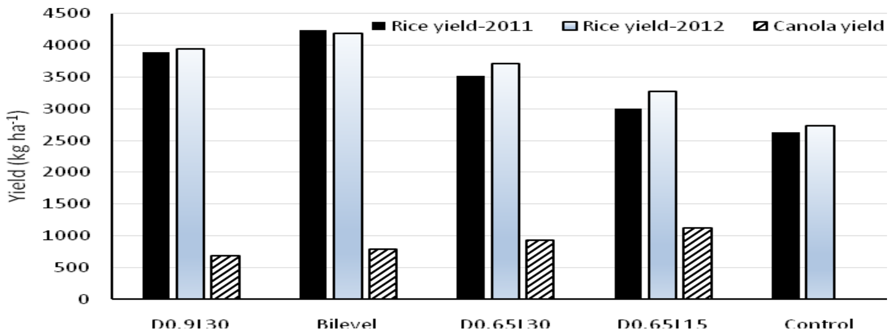


Fig 2: Rice and canola yield under different drainage systems

# 4. Conclusion

The introduction of subsurface drainage and therefore canola cropping provided better utilization of soil nutrients in the study area. During the study period, TP losses of drainage and leaching in the $D_{0.9}L_{30}$, Bilevel, $D_{0.65}L_{30}$, $D_{0.65}L_{15}$, and Control were 1.12, 0.98, 1.47, 1.53, and 24.6 kg ha$^{-1}$, respectively, which are equivalent to about 5.4, 4.8, 7.2, 7.5, and 121 kg triple superphosphate fertilizer. Also, TN losses through drainage and leaching in the $D_{0.9}L_{30}$, Bilevel, $D_{0.65}L_{30}$, $D_{0.65}L_{15}$, and Control were 41, 44.5, 53.6, 48.9, and 265.5 kg ha$^{-1}$, respectively, representing about 89, 96.7, 116.5, 106.3, and 577.2 kg urea losses. Based on the results, crop diversification in the study area, in addition to improving the economic situation of households and at the macro level, improving food security, reduces negative environmental impacts on soil and water resources.

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