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Precipitation and irrigation dominate soil water leaching in cropland in Northern China

Jing Liu[a], Xiaoqing Bi[a], Maoting Ma[a], Lihua Jiang[b], Lianfeng Du[a,*], Shunjiang Li[a], Qinping Sun[a], Guoyuan Zou[a], Hongbin Liu[c]

[a] Institute of Plant Nutrition and Resources, Beijing Academy of Agriculture and Forestry Sciences, Beijing 100091, China
[b] Institute of Agricultural Resources and Environment, Shandong Academy of Agricultural Sciences, Jinan 250100, China
[c] Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China

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ABSTRACT

Studying the effects of precipitation and irrigation on soil water leaching are critical for maintaining agricultural environment in Northern China, where uneven irrigation has been applied coupled with a broad spectrum of climatic conditions. We conducted consecutive a 4-year field experiment from 2008 to 2011 with lysimeters buried 90 cm deep to determine soil water leaching. Results indicated that amounts of soil water leaching in greenhouse croplands were significantly higher than that in open field croplands. Rainy season is the key period for soil water leaching in semi-humid areas in open fields, accounting for 88.6% of the annual amount of leachate, while excess irrigation was a significant factor for soil water leaching in semi-arid areas. Irrigation pattern affects soil water leaching by determining irrigation volume. There was significant leaching with border irrigation, particularly in the Winter-Spring seasons (from Jan. to Jun.), while drip irrigation led to a 62–74% reduction of irrigation water with no leaching happened. With water-saving irrigation, the effects of fertilization on nitrogen leaching were not significant.

1. Introduction

The population boom during the 20th century motivated the implementation of intensive agriculture with all types of crops (e.g., fruit trees, vegetables, and cereals). Unfortunately, agricultural activities probably are the most common sources of diverse forms of pollution (Candela et al., 2008), among which groundwater nitrate pollution is one of the most significant (Muhammetoğlu et al., 2002; Ju et al., 2006). Nitrate loss through leaching has been recognized as one of the most common sources of groundwater contamination. Scientific and public concern have been mounting with respect to the necessity to prevent it (Long and Sun, 2012; Gholamhoseini et al., 2013).

Studies have indicated that soil nitrate concentration and the amounts of subsurface drainage water leaching generates are two important factors that control groundwater nitrate contamination (Asadi et al., 2002; Tamini and Mermoud, 2002; Gholamhoseini et al., 2013; Jia et al., 2014). Nitrate is not retained by soil particles, and it would mobile readily with water flow (Gächter et al., 2004), and higher drainage is associated with greater nitrate leaching (Williams et al., 2015). Heavy irrigation leads to rapid movement of nitrate below the root zone because the percolating water transports it through the profile (Endelman et al., 1974). The mass of nitrate leached in a sandy loam has been found to be related to drainage volume (Ritter et al., 1991; Allaire-Leung et al., 2001). Therefore, the study of agricultural nitrogen pollution necessitates an accurate knowledge of soil water leaching.

Leaching is a process that transports water from the earth's surface underground. Numerous studies have shown that excessive irrigation can cause leaching (Jalali, 2005; Wallis et al., 2011), leading to a strong increase in water percolation into deeper soil horizons (Diez et al., 1997). Factors that affect water percolation in soil, including soil, crop type, irrigation, and nitrogen application, influence the probability of groundwater degradation (Zotarelli et al., 2009; Vaughan and Letey, 2013). Effects of the frequency of ryegrass irrigation on NO_3^--N leaching loss overall differ between the summer and late autumn (Sumanasena et al., 2004). In addition, reports have demonstrated that nitrate leaching is most likely to occur following a heavy precipitation event, while only slight deep percolation has been observed following an irrigation event (Wang et al., 2014). However, these effects on leaching in different climates (such as arid or humid) and different croplands (such as open field or greenhouse croplands) have not been studied. In addition, the load of leaching in scientific reports has been

* Corresponding authors at: Institute of Plant Nutrition and Resources, Beijing Academy of Agriculture and Forestry Sciences, Beijing, 100091, China.
E-mail address: dulianfengyzs@163.com (L. Du).

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determined by many methods, such as direct soil sample analysis, leachate collection from drainage lysimeters, or mathematical simulation models (Meisinger and Gelgado, 2002; Jiang et al., 2010; Min et al., 2012), which have prevented comparisons of the results.

Northern China is one of the most important agricultural production regions in the country with many intensive open field and greenhouse croplands. However, the uneven distribution of rainfall and water shortages cause the agricultural environment to differ greatly from west to east. Within the past decade, many scientific reports showed that nitrate pollution in groundwater was severe in Northern China (Zhang et al., 1996; Liu et al. (2005); Zhao et al., 2007), where excessive N fertilizers and irrigation have been applied in pursuit of high yields (Ye et al., 2010; Sepaskhah and Tafteh, 2012). Some research has been conducted for soil water leaching in this region, only with short-term studies (Zhu et al., 2005; Fang et al., 2010; Wang et al., 2013). They failed to identify the variations and characteristics of leaching under a broad spectrum of climatic conditions and cropping systems in this area, particularly those that have not used the same methods to measure leaching load. Further, there is a general lack of quantitative studies on deep drainage in farmland and little research has been conducted to quantify its influencing factors.

Therefore, from 2008 to 2011, we conducted consecutive a 4-year field experiment to determine soil water leaching losses from grain, open field vegetable, and greenhouse vegetable croplands in Northern China using drainable lysimeters installed at a depth of 90 cm, and observed the changes in rainfall and irrigation simultaneously. The specific objectives of this study were to: (1) determine the current situation of the leached water flux in Northern China, and rainfall and irrigation's effects on it in open field cropland and greenhouse fields, respectively, and (2) identify possible inadequate management practices and propose appropriate measures for water management that will provide local farmers with theoretical guidance on irrigation management to mitigate percolation and nitrate leaching in cropland.

2. Materials and methods

2.1. Experimental sites and treatments

To study soil water leaching in cropland and effects of precipitation and irrigation, three studies involving 9 field sites in Northern China were conducted from 2008 to 2011(Fig. 1). Table 1 shows the patterns of planting and irrigation, soil and texture, and mean annual precipitation and temperature on field sites. The studies were as follows:

2.1.1. Study of rainfall and irrigation's effects on soil water leaching in open field croplands

These experiments were conducted at six open cropland fields, BJL01, BJL02, GSL, HEL, SNL, and JLL (Fig. 1), and the amounts of rainfall, irrigation, and leachate at every site were monitored to study the effects of rainfall and irrigation on soil water leaching in these croplands.

2.1.2. Study on the effects of irrigation pattern on soil water leaching

Experiments were conducted at greenhouse vegetable field SDL (Fig. 1), where two irrigation treatments (border irrigation, M1, and drip irrigation, M2) were carried out to compare their effects on soil water leaching; irrigation amounts are shown in Table 2. Crop species in the experiment were greenhouse cucumber, cultivated two times a year (WS, winter-spring season from Jan. to Jun. and AW, autumn-winter season from Oct. to Dec.). Soil water leachate, irrigation amount each time, and annual irrigation amount were monitored to study irrigation methods' effects on soil water leaching. In addition, the study also was carried out in BJL03, which is under drip irrigation.

2.1.3. Study on the effects of water-saving irrigation on soil water leaching

These studies were conducted in BJL04, which is an organic vegetable production base in Beijing. Two irrigation treatments with the border method (W1, water-saving irrigation, and W2, conventional irrigation) were designed to study water-saving irrigation's effects on soil water leaching. The amount of irrigation during every crop season is shown in Table 3. Three nitrogen levels were applied for each irrigation treatment: N0, no N-fertilizer; N1, optimized N-fertilizer, and N2, conventional N-fertilizer. All fertilizers were applied once with organic N-fertilizer and no dressing.

2.1.4. Sampling and laboratory analysis

Rainfall data were obtained from a meteorological station located approximately 200 m from the field site. In every experimental plot, leached water was collected in leaching trays 0.5 m × 0.4 m buried 90 cm deep with PVC tube, referred to as Technical Specification for Leaching Monitoring (Wu et al., 2014). Leachates were collected within 48 to 96 h after irrigation or rainfall, and their volume was recorded. Nitrate concentration in leachate was detected with Continuous Flow Analysis (Flastar5000) after filtration.

2.2. Statistical analyses

Soil water leaching and water loss rate (formula 1) data were subjected to analysis of variance (one-way ANOVA) to determine the significance of the difference between treatments, the Tukey multiple comparison test to determine the differences among individual treatments, and correlation analysis to test the effects of the influencing factors. All analyses were conducted in the software R with the "psych" (Revelle, 2016) and "agricolae" (Mendiburu, 2013) packages at alpha = 0.05.

Water loss rates = (water loss amount/irrigation amount) × 100% (formula 1)

3. Analysis and results

3.1. Rainfall season is the key period for soil water leaching in open field cropland

The amounts of rainfall and leachate differed among six sites. The range of rainfall from 2008 to 2011 in BJL01, BJL02, GSL, HEL, SNL, and JLL were 0.2–49.1, 0.76–127.56, 1.1–29.7, 4.1–76.9, 1.31–213.62, and 1.2–79.2 mm, respectively. The total amount of rainfall in 4 years was 1211.6, 1346.06, 490.7, 1791.8, 2379.87, and 1198 mm, respectively. Monthly rainfall in the six open field sites is shown in Fig. 2, indicating that rainfall concentrated largely from Jun. to Sept, and accounting for 72.7% of the annual amounts of rainfall.

Correspondingly, leaching also occurred from Jun. to Sept., and the amounts of leachate in BJL01, BJL02, GSL, HEL, SNL, and JLL were 38.9, 59.5, 40.2, 11.1, 7.5, and 14.5 mm, respectively, accounting for 73.0, 90.1, 81.4, 100, 87.1, and 100% of the annual amounts of leachate, respectively. This indicated that the rainy season was the key period for soil water leaching in open field cropland. Amounts of leachate were correlated with rainfall ($p < 0.05$), indicating that soil water leaching was highly consistent with rainfall in open field cropland in Northern China.

3.2. Irrigation has significant effects on soil water leaching in open field cropland

In the six open field sites, soil water leaching was correlated highly with rainfall. However, two sites, GSL and JLL, differed from the others. The amounts of leachate were significantly higher at the GSL site than at HEL, SNL, and JLL, although with relatively lower rainfall amounts than the latter three. In addition, the rainfall at JLL was 594.8 mm, similar to the other sites, BJL01, BJL02, HEL, and SNL, while the amounts of leachate were lower than those at the latter four sites (Fig. 2).