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# Postharvest residual soil nutrients and yield of spring wheat under water deficit in arid northwest China

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ABSTRACT

In areas where two crops are grown per year or three crops every 2 years, the status of residual soil nutrients after the harvest of the first crop is critical to the crop to be grown immediately after, while the postharvest soil nutrient status can be influenced by irrigation applied to the test crop. This study determined the effect of various soil water treatments applied to the test crop on the status of postharvest residual soil nutrient pools in an arid environment. Spring wheat (*Triticum aestivum* L.) was grown as test crop under conditions of full- (as control), high-, moderate-, and low-water conditions during jointing, booting-heading, and grain filling stages, in 2003 and 2004. Compared to the control, grain yield and water use efficiency (WUE) were significantly increased by subjecting the wheat crop to moderate-water conditions during various growth stages, and low-water conditions at jointing stage in both years. Soil C at harvest decreased linearly with increased grain yield of the test crop. Moderate- to high-water conditions during jointing stage resulted in 12–24% greater soil C in the top 40 cm depth in 2003, with a marginal difference in 2004. Water treatments impacted the status of residual soil nutrients in 2003; soil total N and available soil P in the top 40 cm depth were significantly higher in low- to moderate-water treatments compared to the control, while in 2004 significantly higher total N and P, available N, P and K were found only in the top 20 cm depth. Increased yield of wheat test crop with moderate-water resulted in increased postharvest residual soil nutrients, whereas the ratios of C/N, C/P, and C/K were largely influenced by years and were less related to water treatments. We conclude that the determination of postharvest soil C and nutrient elements may provide useful information in monitoring potential changes of soil nutrient status over time in the intensified cropping systems, and that the recommendation of fertilization for the crop to be grown immediately following the first crop can be established by simply analyzing the productivity of the first crop without intensive measurements of soil nutrients.



## 1. Introduction

Soil water and nutrients are the two key factors limiting agricultural productivity in the arid to semiarid areas of northern China (Ogola et al., 2002; Zhang et al., 2005). Deficits of soil water often have substantially negative impacts on the growth and development of major crops such as spring wheat (Lecoeur and Sinclair, 1996; Asseng et al., 1998). However, recent studies have shown that crop yields are not necessarily decreased with a moderate level of water deficit under irrigation conditions (Zhang et al., 1998). In fact, well-regulated deficit irrigation regimes may increase crop yield compared to the crop grown under conditions of free from water deficit (Kang et al., 2002; Deng et al., 2002). The increased crop yield with regulated irrigation is mainly due to the systems allowing crop plants to grow under certain degrees of water stress at non-critical growth stages. However, little is known about whether the effect of the regulated irrigation systems on crop growth is interactively affected by soil nutrients. It is well known that soil fertility is usually reflected by the status of soil nutrients and water together in an integrated system (Zheng et al., 2002).

During the past two decades, significant changes have occurred in agricultural systems in the arid and semiarid areas of northern China. In these areas, traditional production patterns of one crop per year have been expanded to two crops per year or three crops every 2 years. The expanded use of arable lands is to

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produce more gains in a given period of time to meet the growing demands of grains for human food, animal feed, and industrial uses. For example, the area seeded to wheat has doubled in China during the past two decades (Zhang et al., 1998). This is especially true for northern China where a wide variety of field crops have been grown under intensively managed cropping systems. The twelve provinces of northwest China produce 26% of the country's total food supply, in addition to 23% of oil plants, 29% of cotton, 16% of hemp, and 60 % of tobacco of the country total. With the intensive farming systems and overburden of the land use, soil fertility has decreased substantially and soil nutrient deficits have become the second most serious problem behind soil water in these areas. The large amounts of nutrient outputs associated with the removal of grains and straw from the systems have caused deterioration of soil physical and chemical properties (Li, 2002). Soil organic carbon (C) has been declined to a level of 3.5 g $kg^{-1}$ in 2005, along with decreased phosphorus, potassium, and other micronutrients.

In areas with two crops per year, the frost-free period is >160 days on average. The first crop is usually harvested in mid- to late-July and a second crop with a short growth period such as buckwheat (*Eriogonum nidularium* L.) and pearl millet (*Echinochola crusgalli* L.) is seeded immediately after the first crop. Due to hot-dry conditions in July, coupled with low available water, soil C and the status of residual soil nutrients change rapidly. This change of soil nutrient status usually has significant impacts on the choice of the crop to be re-seeded as the second crop during the same season. Understanding the status of residual soil nutrients after the first crop will provide key information for the establishment of fertility recommendation for the second crop within the same year. Also, this information is critically useful in the assessment of the intensive cropping systems for the long term. Therefore, the objective of this study was to determine the status of postharvest residual soil nutrients and their relation to the productivity of the first crop that is grown under various levels of water conditions in the arid environment of northwest China.

## 2. Materials and methods

### 2.1. Study site description

Field experiments were conducted in 2003 and 2004 at Zhangye county in the western region of Gansu Province, PR China (99°23′E longitude, 41°13′N latitude, and 1500 m elevation). The average annual precipitation in this region is 139 mm with the mean annual evaporation (Class A) of 2048 mm. The first part of the growing season (March–July) rainfall was 45 mm in 2003 and 37 mm in 2004, similar to the long-term average of 39 mm (Fig. 1). Due to extremely low rainfall and high evaporation, farming is impossible without irrigation. Daily mean temperatures during the March–July period were 22.0 °C in 2003 and 22.7 °C in 2004, both being similar to the long-term average. The soil at the experimental site was a silt loam with an average soil organic matter of 13.2 g $kg^{-1}$, bulk density of 1.37 g $cm^{-3}$, and pH of 8.47 in the 100 cm depth. The soil in the 0–20 cm depth contained 0.89 g N $kg^{-1}$, 0.89 g P $kg^{-1}$, and 24.3 g K $kg^{-1}$. The field capacity in the 100-cm depth was 22.8%. Some selected physical and chemical properties of the soil are presented in Table 1.

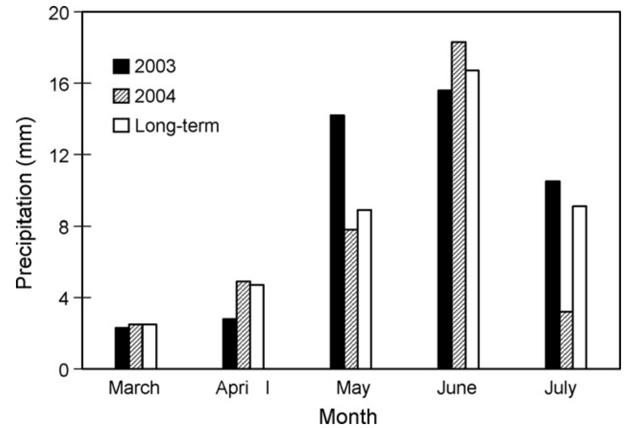


**Fig. 1.** Growing season rainfall at the experimental site of Zhangye, northwest China, in 2003 and 2004 compared with long-term (1970–2000) averages.

### 2.2. Experimental design and plot management

A different piece of land was used for the experiment each year. The land was divided into individual plots of 13.9 m × 3.5 m in size, separated by an area of 1 m buffer zone between plots. Eight water treatments were arranged in a randomized complete block design with three replicates. These treatments were designed to subject the wheat test crop to various degrees of soil water conditions during different stages of crop development as follows: fully (F) watered (soil moisture maintained at 65–70% of the field capacity), high (H) water (soil moisture maintained at 60–65% of the field capacity), medium (M) water (soil moisture maintained at 50–60% of the field capacity), and low (L) water (soil moisture maintained at 45–50% of the field capacity). Spring wheat 'Ningchun no. 18' was grown under these water conditions by varying amounts of irrigation during three wheat developmental periods: (1) jointing, (2) booting-heading, and (3) grain filling (Table 2). In the treatment structure as detailed in Table 2, F meant fully watered, and L, M, and H were low, medium, and high levels of

**Table 2**
Soil moisture contents at three key growth stages of spring wheat grown under various soil water (irrigation) treatments in arid northwest China, 2003–2004.

| Water treatment | Wheat growth stage | | |
|---|---|---|---|
| | Jointing | Booting-heading | Grain filling |
| | % Of field capacity | | |
| FFF | 65–70 | 65–70 | 65–70 |
| HHH | 60–65 | 60–65 | 60–65 |
| HHM | 60–65 | 60–65 | 50–60 |
| MFH | 50–60 | 65–70 | 60–65 |
| MFM | 50–60 | 65–70 | 50–60 |
| MFL | 50–60 | 65–70 | 45–50 |
| LFF | 45–50 | 65–70 | 65–70 |
| LFM | 45–50 | 65–70 | 50–60 |

In the treatment structure, F represents full water (i.e., fully irrigated, free from soil water deficit), and H, M, and L were high, medium, and low levels of soil water, respectively. For example, the treatment "MFH" means the soil water level was maintained at a "Medium" level during the jointing stage, "Full" water during booting-heading stage, and a "High" level during grain filling stage. The similar meanings are applicable to all the other treatments in this table and tables below.

**Table 1**
Some selected physical and chemical properties of the soil at the experimental site before sowing of spring wheat.

| Soil depth (cm) | Organic matter (g $kg^{-1}$) | Total soil N (g $kg^{-1}$) | Total soil P (g $kg^{-1}$) | Total soil K (g $kg^{-1}$) | Available soil N (mg $kg^{-1}$) | Available soil P (mg $kg^{-1}$) | Total salinity (g $kg^{-1}$) | pH | Bulk density (g $cm^{-3}$) | Texture |
|---|---|---|---|---|---|---|---|---|---|---|
| 0–20 | 14.4 | 0.95 | 1.16 | 23.9 | 87.5 | 25.8 | 2.47 | 8.42 | 1.31 | Sandy loam |
| 20–40 | 12.0 | 0.83 | 0.61 | 24.6 | 65.2 | 14.9 | 2.64 | 8.52 | 1.43 | Silt loam |