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# IMPROVING WATER AND NITROGEN USE EFFICIENCY OF POTATO BY PARTIAL ROOT-ZONE DRYING IRRIGATION IN THE SEMI-ARID AREA IN CHINA: A FIELD EXPERIMENTAL STUDY

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**ABSTRACT** Partial root-zone drying irrigation (PRD) has been established as an efficient technology to save water without sacrificing crop yield, but its effectiveness in saving nutrients and hence reducing the impact on soil and water environment is not properly understood. In this paper we present the results of a field experimental with potatoes to demonstrate that PRD can not only save water but also nitrogen. The experiment used secondary treated wastewater, and both subsurface drip and furrow irrigation were investigated. The results indicated that, in comparison with the traditional irrigation method that kept soil water at 90% of the field capacity, alternately keeping half of the roots dry in both subsurface-drip and furrow PRD saved significant amounts of water. In particular the experiment indicated that, in 2008, water use efficiency (WUE) improved by 19.96% and 20.6% when using drip PRD and furrow PRD, respectively. Because of using less water, the PRD also improved nitrogen use efficiency. The measurements of soil nitrogen after harvest revealed that the residual mineral nitrogen in the soil, from 0 to 30cm deep, was reduced by 29.72% and 17.05% under drip PRD and furrow PRD compare to the corresponding full irrigation. Similarly, for soil in depths from 30 to 60cm, this increase to 13.52% and 33.17% under full drip irrigation and full furrow irrigation compare to the corresponding PRD irrigation, indicating a significant decrease in nitrogen leaching when irrigated using drip PRD.

**Keywords:** Nitrogen uptake, Residual nitrogen, Partial root-zone drying, Subsurface drip irrigation, Furrow irrigation.

**1. INTRODUCTION** China is the biggest potato (*Solanum tuberosum*) producing country in the world both in growing area and in potato yield, approximately $730\times10^8$ kg per year, close to one fourth of total tuber yield of the world (FAO, 2006). Due to its sparse and shallow root system, soil water deficit obviously influences tuber yield (Lynch et al., 1995; Porter et al., 1999; Onder et al., 2005; Liu et al., 2006; Shahnazari et al., 2007). Thus, supplementary irrigation is always needed to produce high yielding plants in a semi-arid area. However, until now knowledge on how to improve irrigation water use efficiency (IWUE) and N efficiency of potato by PRD is lacking.

Partial root-zone drying (PRD) and deficit irrigation (DI) had been proven effective water-saving irrigation strategies (Kang and Zhang, 2004). Moreover, PRD has been reported to enhance WUE while maintaining the yield in several crops (Liang et al., 1998; Li et al., 2007; Du et al., 2006, 2008, 2010). The PRD method is to irrigate the plants alternately on different zones of the root system and alternately part of the plant root exposed to drying soil. ( Davies and Zhang, 1991;Kang et al.,1998). As stated above, many studies have been conducted to assess the influence of fertilizer, irrigation strategies, plant species and other factors on the N uptake and WUE by potato (Vos and Van Der Putten, 1997; Vos et al., 1998; Mack and Schjoerring, 2002; Darwish et al., 2003, 2006; Shahnazari et al., 2007, 2008), but the response of soil N residual and uptake to different irrigation management strategies under semi-arid environmental conditions is still not fully understood. The objective of this study was to study how PRD, deficit irrigation (DI) and full irrigation (FI) affect the nitrogen cycle and water use efficiency in the soil-plant system during the whole growth cycle of potato.

## 2. MATERIALS AND METHODS

### 2.1 Experimental site and materials

Field experiments were carried out during 2007 and 2008 at the Agriculture Water and Soil Environmental Field Science Research Station of the CAAS in Xinxiang city, Henan province, China (latitude 35°15′09″N, longitude 113°55′05″E, altitude 73.2m). The climate is temperate with annual average rainfall of about 588.8 mm. Weather data was collected by Automatic Meteorological Station (SkyeLynx MiniMet2 Logger) in the station. Figure 1 shows the seasonal variation of temperature, global radiation, vapor pressure deficit (VPD) and potential evapotranspiration (ETp) during the experimental periods in 2007 and 2008. Reference evapotranspiration (ETp) was calculated according to the formula of Penman-Monteith (Monteith et al., 1990).

The soil was sandy loam. The topsoil (0–0.35m depth) contains 57.75% sand, 30.72% silt, 11.53% clay and 1.15% organic matter. The middle layer (0.35–0.6m depth) contains 56.6% sand, 25.4% silt, 18% clay, and 0.64% organic matter. The subsoil (0.6–1.2m depth) contains 49.92% sand, 34.31% silt, 15.77% clay and 0.47% organic matter.

The soil is classified as an alluvial soil with field capacity (FC) of about 87mm down to the rooting depth of about 60 cm, which for most crops in this soil defines the maximum rooting depth. Soil bulk density for topsoil and subsoil are 1.40 and 1.42 $g.cm^{-3}$, respectively (Li et al., 2009). The retention curve of the topsoil was obtained by pressure plate technique; the curve was derived using the Van Genuchten model on measured observations (Van Genuchten, 1980). Saturated and residual soil water content ($\Theta$) in the root zone was 0.439 and 0.089$m^3$ $m^{-3}$, respectively. Rainfall during whole growth stage of potato in 2007 and 2008 were 50mm and 38.9mm, respectively.

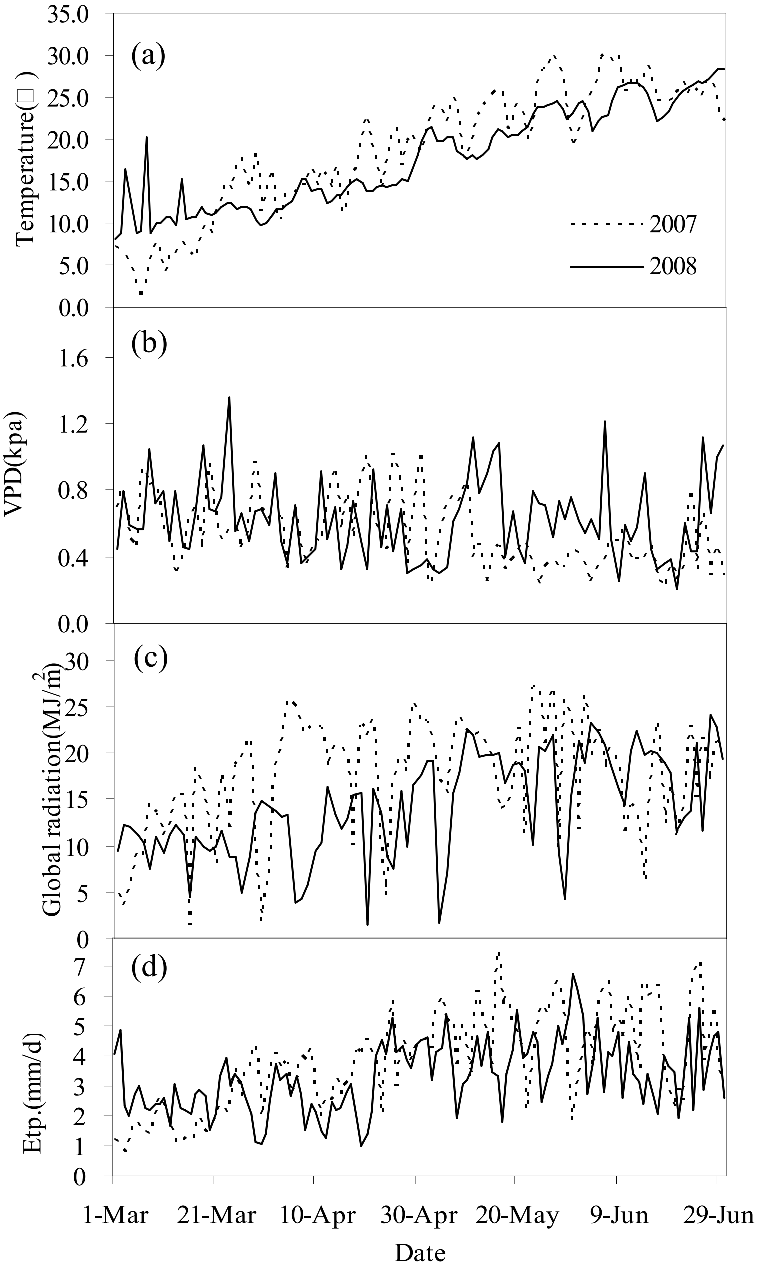


Figure 1. Daily means of temperature (a), vapor pressure deficit (b), radiation (c) and potential evapotranspiration (d) during the experimental period in 2007 and 2008

## 2.2 Experimental design and irrigation treatments

In 2007, the field trial was a fully randomized design with three replicates of two subsurface drip irrigation treatments [full irrigation (FI1), partial root-zone drying (PRD1)] and two furrow irrigation treatments [full irrigation (FI2), partial root-zone drying (PRD2)]. Irrigation scheduling was based on soil water measured with a Time Domain Reflectometer (TDR). Three groups of TDR probes were installed in ridge and in the middle of the neighboring plants (Figure 2(a) and (b)). The FI treatment was irrigated daily to maintain the soil water content at 5–10mm below field capacity during the whole growing season. The PRD treatment received 70% of the irrigation water volume of FI at each irrigation event in which half of the rootzone is irrigated while the other half dries out. PRD started after tuber initiation, 36 days after planting (DAP) and lasted until maturity, 97 DAP. Up to 36 DAP, PRD was irrigated as FI. For more details, see Li et al., (2009).

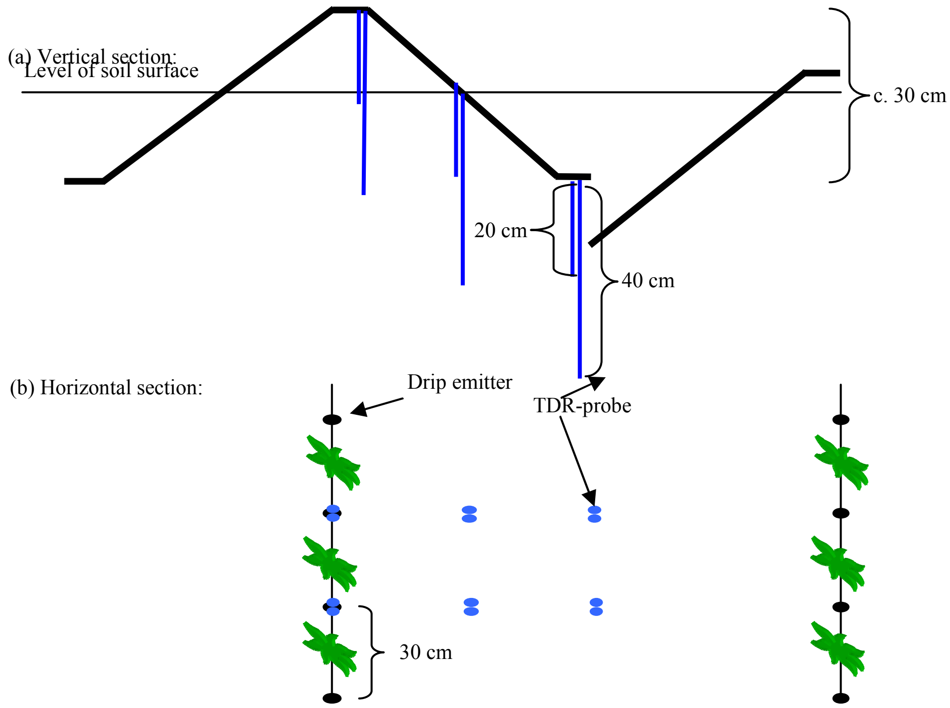


Figure 2. Layout of TDR probes placement in the plots vertical (a) and horizontal section (b)

In 2008, the field trial design was same as the 2007. The FI treatment was irrigated daily to maintain the soil water content at 5–10mm below field capacity during the whole growing season. The PRD treatment received 70% of the irrigation water volume of FI at each irrigation event in which half of the root zone is irrigated while the other half dries out. PRD started after planting (36 DAP) and lasted until maturity (97 DAP). DI and PRD treatments received 70% of the irrigation water amount of FI in each irrigation event during the whole growing season. In PRD treatments the irrigation was alternated between the two drip irrigation lines of the row at 5–10 days interval in 2007 and weekly in 2008. Subsurface drip lines for irrigation were installed in the middle of the ridge 10 cm below the soil surface. For the PRD treatments two drip lines were placed in parallel, positioned at the same depths as in the FI and DI treatments. Other management practices during the whole growth season were completely uniform.

## 2.3 Fertilization

In 2007, fertilizers were applied by ploughing (tractor, YTO-600) at rates of 168.86N kg ha$^{-1}$, 58P kg ha$^{-1}$, 58K kg ha$^{-1}$ as the base fertilizer. Initial N content in the top soil (0-60cm) was 3.18 kg ha$^{-1}$, as measured by the standard methods of the Key Laboratory of High-Efficient and Safe Utilization of Agriculture water Resources of CAAS. In 2008, fertilizers were applied by ploughing at rates of 158.33N kg ha$^{-1}$, 62.5P kg ha$^{-1}$, 62.5K kg ha$^{-1}$ as the base fertilizer. At the period of tuber initiation, fertilizers were applied by irrigation at rates of 37.5N kg ha$^{-1}$, 30P kg ha$^{-1}$, 17.25K kg ha$^{-1}$. At the period of the beginning of flowering, fertilizers were applied by irrigation at rates of 37.5N kg ha$^{-1}$, 30P kg ha$^{-1}$, 17.25K kg ha$^{-1}$. Initial N content of the root zone was 4.30 kg ha$^{-1}$; as measured in the same laboratory.

### 2.4 Crop management

Seedbed preparation was conducted during the early spring. Seed tubers of the Jinyan were pre-conditioned at 14-16°C for about 2 weeks under dim light until they had 5 mm long shoots. Seed tubers were planted as soon as possible, provided the soil temperature at 10 cm depth in the middle of the day was at least 8°C (usually early March). The seed tubers were then placed at a distance of 30 cm apart, 17 cm below ridge level. Subsequently, the drip lines were placed 10 cm below the top of the ridges. Because of a delay in the installation of the irrigation system (laid down late April and operational in May), tubers at the Xinxiang site were planted in early April and some measurements were missed.

### 2.5 Plant sampling and measurements

Plant samples are taken after harvest, 3 samples per plot, stored at room temperature and analysed for $NO_3$-N, $NH_4$-N, Total Nitrogen (TN), Available P (AP), and potassium (AK) in stem and leaf. Tubers were analysed for $NO_3$-N, $NH_4$-N, Total Nitrogen (TN), Total phosphorus (TP), Available potassium (AK). The $NO_3$-N, $NH_4$-N, Total Nitrogen, Available P and Potassium of the filtered aqueous extract were determined on auto analysers (BRAN+LUEBBE ,AA3 , Germany). AP and AK of soil were determined by determinator (SINTEK, STAL-2, Shanghai) (Nelson etal, 1969; Blackmer etal, 1977; Brenner, 1981).

### 2.6 Soil sampling and measurements

Soil samples are taken with a standard 3.5 cm Ø soil auger from soil layers after key growth stage of potato, 5 samples per plot, stored at room temperature and analysed for $NO_3$-N, $NH_4$-N, Total Nitrogen, Total organic C, Available P and Potassium. The $NO_3$-N, $NH_4$-N, Total Nitrogen, Available P and Potassium of the filtered aqueous extract were determined on auto analysers (BRAN+LUEBBE ,AA3 , Germany). TOC of the filtered aqueous extract was determined on a Formacs$^{HT}$ TOC analyser (Skalar, Boom, Belgium). AP and AK of soil were determined by determinator (SINTEK, STAL-2, Shanghai) (Nelson etal, 1969; Blackmer etal, 1977).

### 2.7 Statistical analysis

Analysis of variance (ANOVA) was performed using the general linear model-uni-variate procedure from DPS7.05 software. ANOVAs were done with irrigation method and fertilization level as the main effects and their interaction. All the treatments were compared for any significant differences using the Duncan's multiple range tests at significant level of P0.05 with the DPS7.05 for Windows software package.

## 3. RESULTS

### 3.1 Irrigation and water use efficiency

In 2007, during the PRD treatment period, the full subsurface drip irrigation treatment and full furrow irrigation treatment were irrigated with 58.91mm. For the whole growing season the FI and PRD treatments received 85.30 and 103.77 mm, respectively. The tuber yield of PRD1, FI1, PRD2, FI2 was 9.62±0.35, 9.64±0.58, 7.48±1.15, 6.31±0.54 t $ha^{-1}$, respectively (Table 1). The PRD treatments were not significantly different from full irrigation ($p < 0.05$). The irrigation water use efficiency (IWUE) was calculated as the ratio of total fresh tuber (TFT) weight to irrigation water amount (IWA) for the whole growth season, IWUE=IFT/IWA(kg $mm^{-1}$) (Michael, 1978; Cooper et al., 1991; Ali et al., 2007; Ali et al., 2008). IWUE of PRD1, FI1, PRD2, FI2 was 112.82±4.10, 92.87±5.57, 87.75±3.46, 60.85±5.21 kg $ha^{-1}$ $mm^{-1}$, respectively. The IWUE of the PRD treatments was significantly higher than that of FI ($p < 0.05$). In 2008, the PRD1, FI1, PRD2 and FI2 treatments received 131.9, 174.5, 166.1 and 219.3 mm during the growing season, respectively. The tuber yield of PRD1, FI1, PRD2, FI2 was 18.65±1.30, 20.88±2.20, 16.49±1.27, 18.57±1.07 t.$ha^{-1}$, respectively. The tuber yield of the PRD treatments was not significantly different from that obtained under full irrigation ($p<0.05$). The IWUE (irrigation water use efficiency, IWUE = total fresh tuber/ irrigation water amount) of PRD1, FI1, PRD2, FI2 was 141.42±2.27, 119.65±6.94, 99.3±1.69, 84.7±4.56 kg $ha^{-1}$ $mm^{-1}$, respectively. The PRD1 treatments had significantly higher IWUE than FI1, by 18.19%. The PRD2 treatments had significantly higher IWUE than FI2, by 17.24% ($p < 0.05$).

Table 1 Irrigation amount and irrigation water use efficiency of different treatments in 2007 and 2008

| Year | Treatments | Pre-irrigation (mm) | First irrigation (mm) | Second irrigation (mm) | Third irrigation (mm) | Total amount (mm) | Yield (t/ha) | IWUE (kg/ha mm) |
|---|---|---|---|---|---|---|---|---|
| 2007 | PRD1 | 34.72 | 10.14 | 15.94 | 24.50 | 85.30 | 9.62a | 112.82a |
| | FI1 | 34.72 | 10.14 | 22.78 | 36.13 | 103.77 | 9.64a | 92.87b |
| | PRD2 | 34.72 | 10.14 | 15.94 | 24.50 | 85.30 | 7.48b | 87.75b |
| | FI2 | 34.72 | 10.14 | 22.78 | 36.13 | 103.77 | 6.31b | 60.85c |
| 2008 | PRD1 | 22.50 | 35.20 | 30.80 | 43.40 | 131.90 | 18.65AB | 141.42A |
| | FI1 | 22.50 | 46.00 | 44.00 | 62.00 | 174.50 | 20.88A | 119.65B |
| | PRD2 | 22.50 | 43.90 | 47.80 | 51.90 | 166.10 | 16.49B | 99.30C |
| | Full2 | 22.50 | 54.20 | 68.40 | 74.20 | 219.30 | 18.57B | 84.70D |

Different letters show significant differences at the 95% level for comparison between irrigation treatments. IWUE means irrigation water use efficiency.

### 3.2 Total mineral nitrogen (Nmin) content in potato

Total Nmin content in tuber, stem and leaf of all of irrigation treatments are shown in Figure 3. In 2008, total residual Nmin for PRD1, FI1, PRD2 and FI2 were 97.50±1.57, 93.47±5.42, 80.90±1.37 and 81.01±4.36 kg $ha^{-1}$, respectively. The residual Nmin for

PRD1 and PRD2 treatments was not significantly different when compared with FI1 and FI2 ($p < 0.05$). It could be concluded that roots of potato enhanced soil N intake after water supply under appropriate water deficit pressure (Shahnazari et al., 2008).

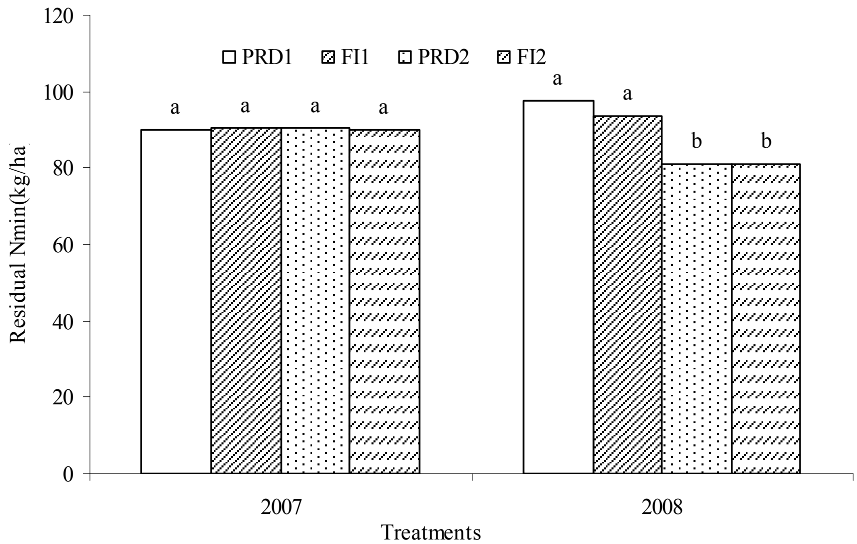


Figure 3 . The residual Nmin content in plants after harvest for different treatments in 2007 and 2008. Different letters show significant differences at the 95% level for comparison between irrigation treatments.

### 3.3 Residual N in soil

The $NO_3$-N, $NH_4$-N and Nmin content in 2007, 2008 of different treatments measured were shown in Figure 4 and Figure 5. The residual $NO_3$-N and $NH_4$-N in the soil layers were measured for all treatments at the end of the season. The residual $NO_3$-N in different soil layers in 2007 was shown in Figure 4(a). In the top layer (0-30cm) soil residual $NO_3$-N content for PRD1, FI1, PRD2 and FI2 was 231.31±11.5, 303.29±14.5, 229.19±11.5 and 269.7±13.0kg $ha^{-1}$, respectively. The upper soil residual $NO_3$-N content for PRD1 and PRD2 was lower than for FI1 and FI2, 23.73% and 15.02%, respectively. In the deeper layer (30-60cm), residual $NO_3$-N content for PRD1, FI1, PRD2 and FI2 was 86.5±4.51, 99.12±5.01, 64.16±3.06 and 88.64±4.36 kg $ha^{-1}$, respectively. The residual $NO_3$-N content of the deeper soil layer for PRD1 and PRD2 was lower than FI1 and FI2, 12.73%, 27.62%, respectively. The residual $NO_3$-N in different soil layers in 2008 was shown in Figure 5(a). In the top layer (0-10cm), the maximum and minimum residual $NO_3$-N content was 180.78 and 39.93 kg $ha^{-1}$, which was found in FI1 and FI2. Residual $NO_3$-N content in PRD1 and PRD2 was significantly lower in the layers(0-10, 10-20, 20-30, 30-40, 40-60cm)compared with the FI1 and FI2 treatments ($p < 0.05$). It can be conclude that the soil residual $NO_3$-N in FI treatments is higher than PRD treatments.

The residual $NH_4$-N in different soil layers during 2007 was shown in Figure 4(b). In the top layer (0-30cm) soil residual $NH_4$-N content for PRD1, FI1, PRD2 and FI2 was 7.56±0.93, 6.56±0.8, 9.59±1.17 and 9.78±1.19 kg $ha^{-1}$, respectively. The ratio of $NH_4$-N with $NO_3$-N range in the upper layer (0-30cm) was 2.16% to 3.17%, the ratio of $NH_4$-N and $NO_3$-N range in the deeper layer was 7.33% to 16.07%. The residual $NH_4$-N in different soil layers during 2008 was shown in Figure 5(b). In the top layer (0-10cm) soil residual $NH_4$-N content for PRD1, FI1, PRD2 and FI2 was 0.19±0.07, 0.09±0.07, 0.17±0.05 and 0.16±0.1 kg $ha^{-1}$, respectively. The ratio of $NH_4$-N with $NO_3$-N range in the soil layer was 0.05% to 1.05%. For all soil layers, residual $NH_4$-N content for PRD1 and PRD2 was not significantly different when compared with the FI1 and FI2 treatments ($p < 0.05$).

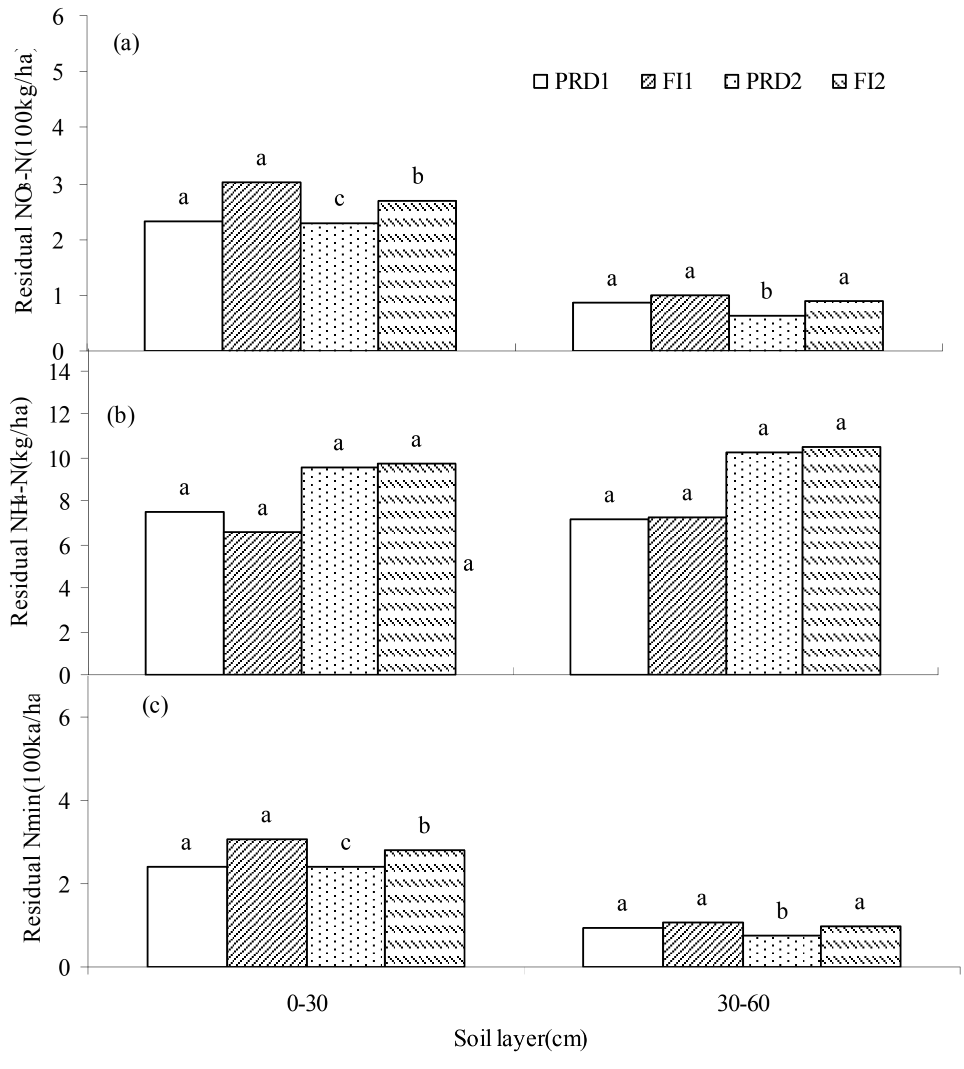


Figure 4 Residual $NO_3$-N(a), $NH_4$-N(b) and mineral N[Nmin](c) content in different soil layers in 2007 with partial rootzone drying under subsurface drip irrigation (PRD1), full irrigation under subsurface drip irrigation(FI1), partial rootzone drying under furrow irrigation (PRD2) and full irrigation under furrow irrigation (FI2).

The residual Nmin of 2007 and 2008 in different soil layers were shown in Figure 4(c) and Figure 5(c). Based on the above results the total residual Nmin content decreased from the topsoil to the deeper layers in subsurface drip irrigation. However, the maximum residual Nmin content for PRD2 and FI2 appeared in the third layer (20-30cm), 77.02±8.4, 89.25±4.18 kg $ha^{-1}$, respectively. The minimum residual Nmin content for PRD2 and FI2 appeared in the second layer and the top layer, 43.14±10.15 and

40.09±4.24 kg $ha^{-1}$, respectively. The residual Nmin in the layers (0-10, 10-20, 20-30, 30-40, 40-60cm) for PRD1 and PRD2 has significantly lower than for the FI1 and FI2 treatments.

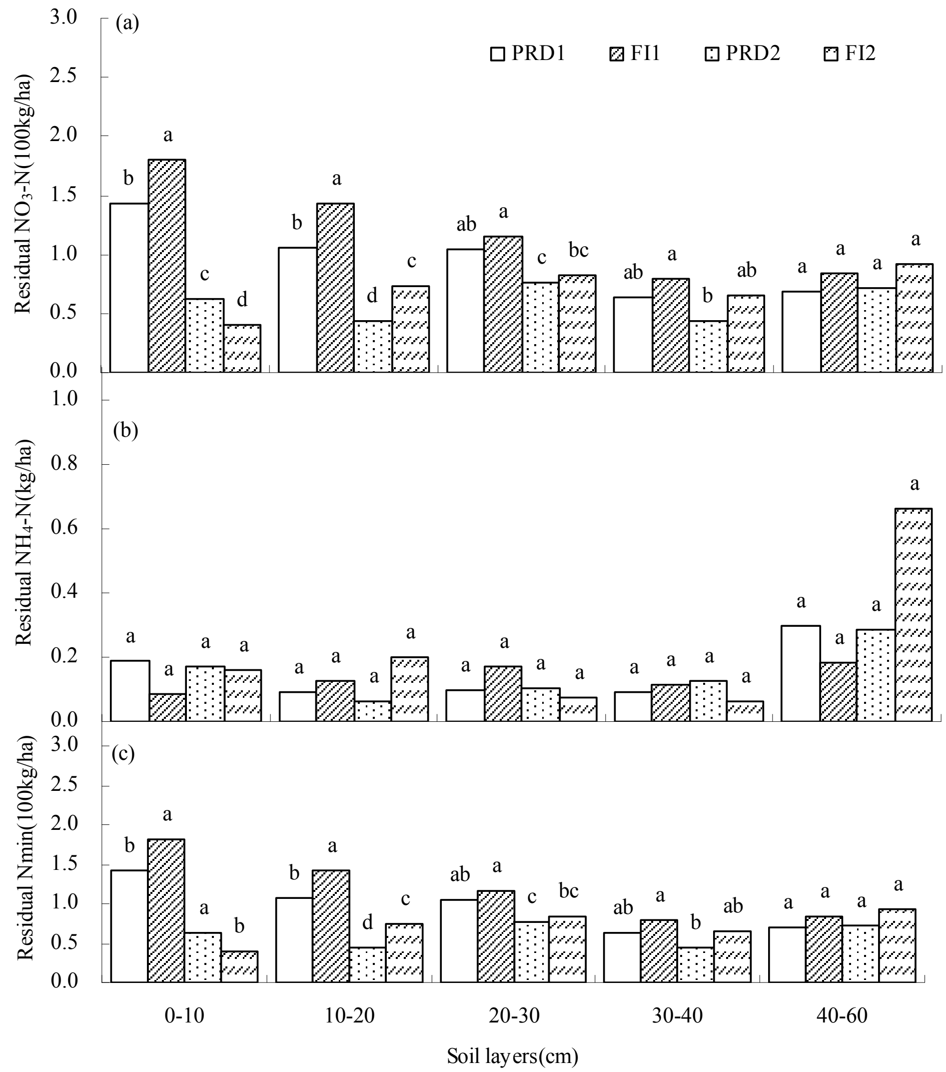


Figure 5 Residual $NO_3$-N(a), $NH_4$-N(b) and minernal N[Nmin](c) content in different soil layers in 2008 with partial rootzone drying under subsurface drip irrigation(PRD1), full irrigation under subsurface drip irrigation (FI1), deficit irrigation under subsurface drip irrigation (DI1), partial rootzone drying under furrow irrigation (PRD2) and full irrigation under furrow irrigation (FI2). Different letters show significant differences at the 95% level for comparison between irrigation treatments in the soil layers (0-10, 10-20, 20-30, 30-40, 40-60cm).

The N balance variables determined in 2007 and 2008 for different treatments measured were shown in Table 2. The residual Nmin after harvest in 2007 for PRD1, FI1, PRD2 and FI2 was 318.21±15.53, 402.87±19.66, 293.78±14.35 and 358.83±17.52 kg $ha^{-1}$, respectively. The residual Nmin after harvest in 2008 for PRD1, FI1, PRD2 and FI2 were 483.08±14.85, 599.55±20.35, 294.23±6.34 and 355.55±15.28 kg $ha^{-1}$, respectively. The residual Nmin after harvest in 2007 and 2008 for PRD irrigation was significantly lower compared with full irrigation. The physiological N use efficiency (PNUE) for PRD1 and

PRD2 were significantly lower than FI1 and FI2 in 2008. The agronomic N use efficiency for PRD2 were significantly higher than F2 in 2007.

Table 2. Nitrogen balance in the plant–soil system and nitrogen use efficiency of different treatments in 2007 and 2008

| Year | Treatments | N uptake by plant (kg/ha) | Residual Nmin after harvest (kg/ha) | Nmin before planting (kg/ha) | Fertilizer (kg/ha) | N content in water (kg/ha) | *PNUE* | *ANUE* |
|---|---|---|---|---|---|---|---|---|
| 2007 | PRD1 | 85.53a | 318.21c | 318.00 | 168.86 | 29.59 | 108.71a | 48.49a |
| | FI1 | 88.97a | 402.87a | 318.00 | 168.86 | 35.60 | 108.32a | 47.14a |
| | PRD2 | 88.27a | 293.78c | 318.00 | 168.86 | 29.59 | 84.80b | 37.72b |
| | FI2 | 85.74a | 358.83b | 318.00 | 168.86 | 35.60 | 73.64b | 30.88c |
| 2008 | PRD1 | 97.50A | 483.08B | 546.91 | 233.33 | 45.75 | 194.71B | 68.02A |
| | FI1 | 93.47A | 599.55A | 583.97 | 233.33 | 60.52 | 209.13A | 66.52A |
| | PRD2 | 80.90B | 294.23D | 268.89 | 233.33 | 57.61 | 200.80B | 55.84B |
| | FI2 | 81.01B | 355.55C | 346.37 | 233.33 | 76.06 | 229.30A | 60.04B |

PNUE means physiological N use efficiency, PNUE equal to ratio of yield with plant uptake N. ANUE means agronomic N use efficiency, ANUE equal to ratio of yield with total N supplied.

## 4. DISCUSSION

In this study, when compared with the FI treatment, PRI and DI slightly reduced the total dry mass under the same fertilization level. But PRD saved water consumption of potato by 24.41% to 32.03%, and thus increased IWUE by 15.47–18.19%. Our results are in agreement with some previous reports (Liang et al., 1998; Li et al., 2007; Shahnazari et al., 2008). Kang et al. (1998) indicated that, compared with conventional watering, PRD reduced water consumption of maize by 35% with a slight reduction in total biomass. The mechanism of PRD alternates wetting and drying of the soil profile in the rootzone, by which it allows the plant to explore root-sourced Abscisic acid (ABA) signalling to regulate plant physiology (Dry et al., 2000; Liu et al., 2006), stimulates root growth after water is supplied (Davies and Hartung, 2004), and leads to similar yield comparable with FI treatment (Du et al., 2006).

The tuber and leaf TN content of potatoes for PRD is higher than for FI. PRD enhanced N accumulation in the plant by 2.82-11.19%. Our result was in accordance with previous reports (Shahnazari et al., 2008). The residual $NO_3$-N and mineral N for PRD after harvest were significant lower than for FI, whether it concerned subsurface drip or furrow irrigation. This might be due to PRD which can stimulate mineralization of organic nitrogen, thus enhancing nitrogen availability in the rootzone soil (Lundquist et al., 1999; Bilas et al.,2006; Vale et al., 2007). Optimal alternate wetting and drying of part of the rootzone, maintains the soil water potential in a suitable range which increases microbial activity (Jaap et al., 1992; Xiang et al., 2008). In other words, PRD might have avoided the dehydration and hypoxia which result from the excessive water in the FI treatment, thereby the microbial activity under PRD was increased as a result of such wetting and drying cycle (Wang et al., 2008; Yu et al., 2008; Li et al., 2010). Li et al. (2010) indicate that PRD increases soil enzymatic activities under optimum ratios of inorganic to organic nitrogen fertilizers.

In this study, the residual $NO_3$-N and mineral N for subsurface drip irrigation decreased from top layer to lower layers. However, the maximum value of residual $NO_3$-N and mineral N for furrow irrigation appeared in the third layer (20-30cm), 76.92 and 82.88 kg $ha^{-1}$, respectively. The residual N for furrow irrigation first increased and then decreased from top layer to lower layers. This might be due to furrow irrigation which enhanced the nitrogen transfer to lower layers under larger irrigation amounts compared with subsurface irrigation (Crevoisier et al., 2008).

## 5. CONCLUSIONS

Potato is very sensitive to water deficit and tuber yield would be reduced by soil water stress (Porter et al., 1999; Liu et al., 2006). But in Henan province, potato is grown with supplementary irrigation under low rainfall conditions. The study results might be useful in areas where deficit irrigation and soil quality maintenance are needed in crop production. Based on 2 years field experiments on sandy loam soil under semi-arid environment we conclude that:

(1) PRD treatment improved IWUE and soil mineral N availability, and maintained tuber yield if a suitable irrigation schedule and alternate cycle are applied.

(2) Furrow irrigation strategies, whether PRD or FI, could transfer more soil residual nitrogen to lower layers compared with subsurface drip irrigation. This might involve the risk of soil nitrogen leaching and shallow groundwater pollution.

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