RESEARCH

Improving Potato Yield, Water Productivity and Nitrogen Use Efficiency by Managing Irrigation Based on Potato Root Distribution

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Abstract

Potato is a typical shallow-root crop and a good understanding of its root distribution is critical in potato water management, which is especially important for potato production in areas such as Inner Mongolia where water resource is limited. We conducted field experiments to investigate the dynamic distribution of potato root in the soil, then used this as a basis to design a new irrigation method for potato production in the region; effects of the improved irrigation and conventional method were analyzed as well by measuring plant growth, yield, water productivity and nitrogen use efficiency. The results showed that large difference existed in root distribution of potato plants at different growth stages in Inner Mongolia, suggesting the present water management strategy of uniform irrigation during potato production is inefficient and has great potential for improvement. Adjusting irrigation amount so that the wet soil zone depth covered 80% of root distribution during potato growth significantly increased water productivity, decreased N leaching, improved N absorption, nitrogen use efficiency and plant growth, leading to increased tuber yield. Therefore, the improved water management method can be used extensively.

Keywords Root distribution · Potato growth stage · Water application time · Wet soil depth · Nitrogen residual in soil

Introduction

Inner Mongolia ranks the first in potato production in China due to its ample solar radiation, large temperature difference between day and night, and light textured soil favoring potato production (Jia et al., 2018a). However annual precipitation in the area is less than 300 mm, and the precipitation during potato growth is only about 150 mm, therefore average yield in this region can hardly reach 10 Mg/ha without irrigation (i.e. the yield under rainfed condition). To achieve higher yield and profits from potato production, irrigation amount has been increasing, and dependency on groundwater has been increased, resulting in the drilling of more and

deeper wells in the region during the past 20 years, causing underground water level to drop significantly. Traditional flood irrigation method in potato production has low water productivity and is contributing to an increasingly severe water crisis in the region (Shi et al., 2015). In addition, due to over irrigation in potato production, there has been significant increase in the leaching of nitrogen fertilizer into deep soil layer, rendering it unavailable for uptake by potato roots, therefore nitrogen fertilizer use efficiency dropped from 45% in the 1950s to less than 20% nowadays (Chen et al., 2012), resulting in more fertilizer being used in potato production. More than 17% of N fertilizer supplied to potato fields was lost via leaching in the region, causing greater environmental risk since nitrate concentration in groundwater near potato farmland could reach 87.4 mg/L, far exceeding the threshold of China's drinking water standard of 20 mg/L (Qin et al., 2013; Yang et al., 2018).

Drip irrigation technique was recently introduced into potato production in the region and has been shown to increase water and fertilizer use efficiencies simultaneously, minimizing the cost of irrigation and fertilizers with notable economic savings, therefore drip fertigation was generally considered as the optimal choice for potato production in Inner Mongolia where sandy soils are dominant, and nitrate

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leaching is the most important source of N loss (Jia et al., 2018b; Yang et al., 2018). However, current irrigation method uses equal volume of water each time, achieving 60% of maximum water holding capacity of soil in 1 m, but does not take crop developing stage and its rooting depth into account. Therefore, the irrigation quota may need to be improved so that water productivity could be increased further.

Plant root system is the major organ for water absorption, therefore understanding plant root distribution in soil layers is the basis for reasonable water management. Potato is usually a shallow-rooted crop (Alva et al., 2011; Fixen & Bruulsema, 2014; Hu et al., 2012; Iwama, 2008), its roots mainly distributed in the upper 30 cm of soil (Iwama, 2008). However, this varies with soil texture, and some may reach 1 m of soil depth (Ahmadi et al., 2011; Hu et al., 2012; Jones, 1983). In addition, potato root distribution in soil also varies with growth stages (Lesczynski & Tanner, 1976), which are critical for crop management. However, root studies are generally very time and labor consuming, and no study has been done to investigate root distribution during potato growth in the sandy soil of Inner Mongolia. Therefore, the first objective of this study was to examine the distribution dynamics of potato roots in the soil of Inner Mongolia.

Wetted soil depth and volume under a drip emitter is affected by soil texture, which needs to be considered in determining the appropriate irrigation amount (Zur, 1996). Schwartzman and Zur (1986) proposed an equation to calculate the irrigation amount per emitter for certain wet soil depth, provided the saturated water conductivity of the soil is known. Thus, it is easy to design a drip irrigation scheme for maximally matching the wetted soil depth with the spatial distribution of potato roots in the soil, which may increase water productivity. Therefore, the second objective of this study was to design a new irrigation method for matching the wetted soil depth with the spatial distribution of potato roots in the soil of the region, and to test the effect of the new irrigation method on plant growth, tuber yield, water productivity, and nitrogen use efficiency.

Materials and Methods

Experiment 1: Observation of Potato Root Distribution

Experiment Description

Field experiment for observation of root spatial and temporal distribution of potatoes was conducted in 2018. In order to make the results solid, two typical sites, Chayouzhongqi (at 41° 30′ N, 112° 64′ E and an altitude of 1780 m)

and Siziwangqi (at 41° 30′ N, 111° 40′ E and an altitude of 1400 m) were chosen, where potato is usually planted in early May and harvested in early September. Soils of both sites are sandy loam, and basic physical and chemical properties of the soil 0–40 cm deep at the fields and the precipitation in the experimental years are shown in Table 1. The frost period is about 100 d, from mid-May to early September. Four plots were arranged at each site, each plot covered 90 m², and contained potato plants (cultivar Kexin-1) in rows 90 cm apart with 30 cm between plants within a row. Plants were watered 8 times (225 m³/ha of water each time) using a drip irrigation system during the growth period. Urea was applied to give a nitrogen application rate of 300 kg/ha, and 30% of the urea was broadcast at sowing with the other 70% drip fertigated during the growth period. Potassium sulfate and calcium superphosphate were added to give a K_2O application rate of 300 kg/ha and P_2O_5 180 kg/ha respectively at sowing. Potato seed tubers were sown on May 6 and May 4 at Chayouzhongqi and Siziwangqi, respectively, and plants were harvested on September 10 and September12 at the two sites respectively.

Root Sampling and Measurement

For analyzing root distribution in soil during potato growth, at stages of seedling, tuber initiation, tuber bulking, and starch accumulation, three areas of 120 cm × 90 cm size were randomly sampled in each plot. Each sample contained 4 potato plants. Vines were cut before soil and root sampling. Every 10 cm depth of soil with roots were sampled till 120 cm depth. Soil was passed through a sieve and roots were collected. After rinsing, root samples were dried to a constant weight at 80 °C and weighed.

Experiment 2: Establishment of New Irrigation Method

Experimental Design and Field Layout

The experiment was performed at Chayouzhongqi in 2019, 2020 and 2021, using a randomized block design, with four replicates for each treatment. Each plot covered 280 m², contained potato plants (cultivar Kexin-1) in rows 90 cm apart with 30 cm between plants within a row. The basic soil physical and chemical properties were shown in Table 1. Plants were watered using a drip irrigation system. 300 kg/ha of K_2O and 180 kg/ha of P_2O_5 were added at sowing. Nitrogen application rate was 300 kg/ha, with 30% of the N broadcast at sowing and the other 70% drip fertigated during the potato growth period. In 2019, potato seed tubers were sown on May 6 and harvested on September 8; in 2020, potato seed tubers were sown on May 1, and harvested on

Table 1 Basic physical and chemical properties of the soil (0–40 cm deep) at the experimental sites and the precipitation in the experimental year

Year	Site	Soil organic matter (g/kg)	Total N (g/kg)	Olsen P (mg/kg)	NH$_4$OAc-exchangeable K (mg/kg)	Soil texture	Soil bulk weight (g/cm^3)	Field capacity (%)	pH	Precipitation during potato growth (mm)
2018	Siziwangqi	24.6	1.43	13.5	132.5	Sandy loam	1.38	23.42	8.1	124
2018	Chayouzhongqi	22.4	1.36	12.9	126.3	Sandy loam	1.41	21.99	8.0	102
2019	Chayouzhongqi	21.9	1.39	12.2	127.9	Sandy loam	1.40	23.08	8.1	100
2020	Chayouzhongqi	23.5	1.41	13.6	128.7	Sandy loam	1.41	22.37	8.1	154
2021	Chayouzhongqi	24.8	1.65	13.1	130.4	Sandy loam	1.41	22.79	8.0	125

September 9, in 2021, potato seed tubers were sown on May 2 and harvested on September 9.

Irrigation Treatments

Two treatments were implemented in the experiment. Treatment 1 (T1) was conventional irrigation, and potato plants were irrigated 8 times during potato growth period with 225m^3/ha of water each time (Table 2). For treatment 2 (T2, Improved irrigation), total irrigation volume and irrigation times were the same as those of T1 (1800 m^3/ha for 8 times), however, single irrigation volume was calculated as Vi = 37,037 * V, where V is the water volume supplied by each drip emitter at each irrigation time, 37,037 is the total number of emitters per ha. V was calculated based on the model proposed by Schwartzman and Zur (1986):

$$V = \left(\frac{Z}{2.54} \left(\frac{q}{K_s} \right)^{0.45} \right)^{\frac{1}{0.63}} \tag{1}$$

where Z is the vertical depth (m) of wet soil; q is the dripping rate of each emitter (m^3/h), which is 2.2 L/h at a pressure of 0.1 MPa used presently in potato production; Ks is soil saturated water conductivity (m/s), which was calculated as 4.26×10^{-6}–6.04×10^{-6} m/s for different soil layers according to Shao et al (2006). When Z is replaced by the depth of soil in which 80% of potato roots are distributed (based on the results of experiment 1), V can be calculated with the equation above. Single irrigation volumes were listed in Table 2.

Sampling and Measurement

Plant samples were taken at 15, 30, 45, 60 and 75 days after emergence (DAE). At each sampling time, five plants in each plot were sampled at random, and the leaves, stems, roots, and tubers were collected. The fresh weight of each plant part was recorded, and leaf area was measured using a plant leaf scanner (LA-S, Hangzhou, China). Then, tissues were dried to a constant weight at 80 °C, and plant dry weight was calculated as the sum of dry weight of each plant part. Each dry sample was ground and passed through a 0.25 mm sieve, and each ground sample was digested in a mixture of H$_2$SO$_4$ and H$_2$O$_2$ to determine the total nitrogen concentration using the Kjeldahl method (Bao, 2008). Soil samples in increments of 20 cm from 0 to 100 cm depth under each drip emitter for both treatments were taken before harvest to determine soil nitrate content. Soil nitrate was extracted by 2 mol/L KCl solution, and nitrate in the solution was determined spectrophotometrically using Continuous Flow Analyzer System (SKALAR SAN++, Netherlands).

Table 2 Single irrigation treatments for experiment 2	Treatment	Total irrigation volume (m³/ha)	Days after emergence (DAE)							
			5	15	24	31	38	45	55	65
	T1	1800	225	225	225	225	225	225	225	225
	T2	1800	90	90	195	195	345	345	345	195

At the end of the experiment, potatoes in 5.4 m² of each plot were harvested and the tuber yields were calculated as Mg/ha. Potatoes weighing 150 g or more were defined as marketable tubers (Men & Liu, 1995).

Soil water content in field experiments was determined before sowing and after harvest. Three soil sampling points were randomly selected for each plot at each sampling time. At each point, five samples, each from a 20 cm layer, were collected in sealed plastic envelopes and brought back to the lab. After weighing, soil samples were dried in an oven set to 105 °C until constant weight was obtained for determination of soil water content.

Statistics and Calculations

Differences in treatments were analyzed using a one-way analysis of variance (ANOVA), a Tukey test was used for multiple comparisons, and $p < 0.05$ was considered statistically significant. SPSS 24.0 software (IBM, Armonk, NY, USA) was used for statistical analysis.

Potato Water Productivity (WP) was calculated by the following equation (Fernández et al., 2020):

$$WP = Y/ET \tag{2}$$

where Y is fresh tuber yield, and ET is evapotranspiration during potato growth. Since surface runoff, deep drainage, and groundwater recharge were all negligible in this study, ET = water applied through irrigation + precipitation during the growing season + soil water storage before sowing − soil water storage after harvest.

Leaf area index (LAI) was calculated as:

$$LAI = LA/L \tag{3}$$

where LA is total leaf area of plants sampled, and L is the area of the land in which the sampled plants grew.

Partial factor productivity of nitrogen fertilizer (PFP_N,) was calculated by the following equation:

$$PFP_N = Y/F_N \tag{4}$$

where Y is fresh tuber yield (Mg/ha), F_N is nitrogen fertilizer application rate (kg/ha). In this study, PFP was used to assess potato nitrogen use efficiency, i.e., potato yield produced per unit N applied.

Marketable potato rate (M) was calculated after Men and Liu (1995):

$$M = Y_M/Y * 100\% \tag{5}$$

where Y_M is yield of the tubers weighing 150 g or more, Y is yield of total tubers.

Potato dry matter accumulation (DM) was calculated as DM = dry weight/plant × plant density.

Results

Potato Root Distribution in the Soil

Results from Experiment 1 showed that potato root distribution varied greatly with its growth stages (Fig. 1). Roots of potato plants were mainly confined to the top 20 cm of soil at seedling stage, which accounted for 93–95% of total root weight. The mean root dry weight at this stage was 2.03 and 2.20 g/plant respectively at Chayouzhongqi and Siziwangqi. At tuber formation stage, potato roots reached a depth of 40 cm, and the mean root dry weight was 3.69 and 4.18 g/plant respectively at the two sites, about twice that of the seeding stage; roots in the 0–20 cm soil layer accounted for 62–68% of total root weight, those in the 20–30 cm soil layer accounted for 20–22%, and 12–16% of roots were distributed in the 30–40 cm soil layer. At tuber bulking stage, potato showed further deeper root development. Roots reached a depth of 70 cm, and more roots were distributed in deep soil layer: 49–52% of the root was distributed in the 0–20 cm soil layer, 36–37% of the root was distributed in the 20–40 cm layer, and 12–15% of the root reached the soil layer of 40–70 cm; the mean root dry weight was 4.50 and 5.14 g/plant respectively at the two sites. At starch accumulation stage, 69–71% of the root was distributed in the 0–20 cm soil layer, 23–25% of the root was distributed in the 20–40 cm soil layer, and in the 40–60 cm layer, roots accounted for about 6% of the total.

Fig. 1 Spatial and temporal distribution of potato roots at the two sites (**A**: Cahyouzhongqi; **B**: Siziwangqi)

A Chayouzhongqi

B Siziwangqi
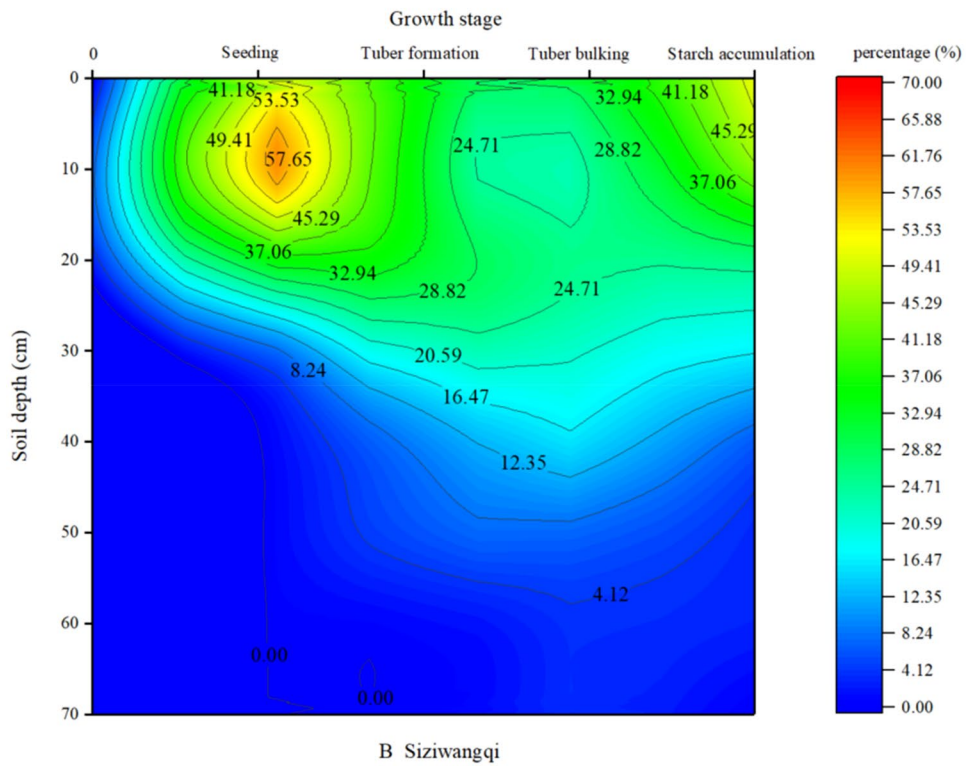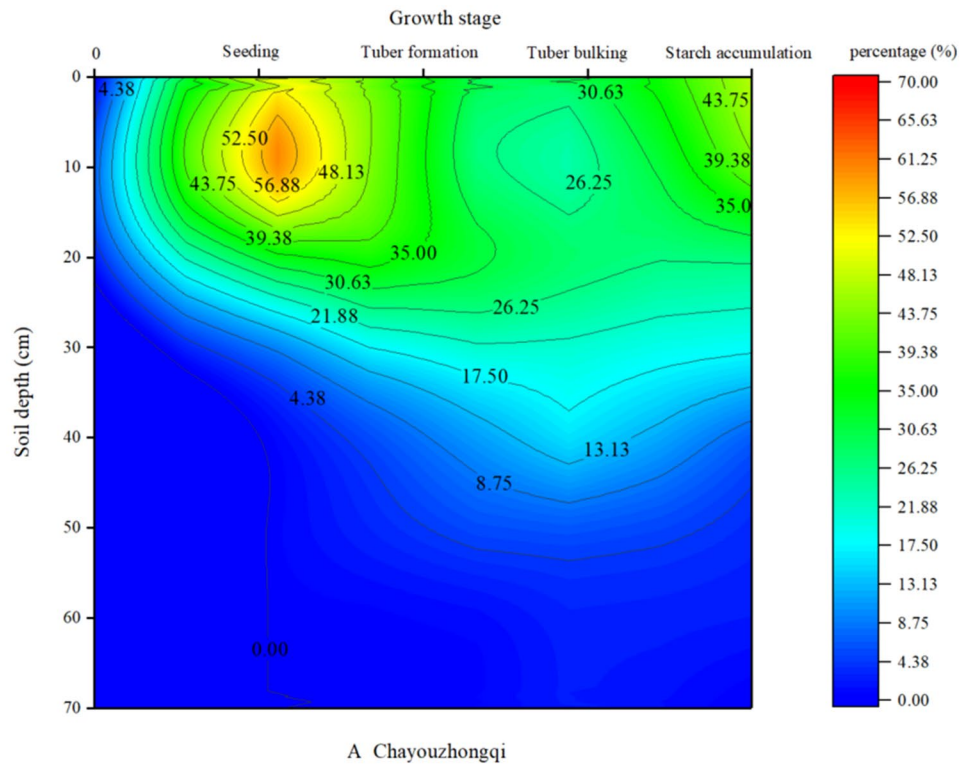
Table 3 Effect of different irrigation strategies on the accumulation of dry matter (DM), leaf area index (LAI) and shoot:root ratio of potato plants at different growth stages

| Year	DM LAI shoot:root	Treatment	Potato growth stage				
			Seedling	Tuber formation	Tuber bulking	Starch accumulation	Harvest
2019	DM (kg/ha)	T1	444 a	2427 b	6033 b	11,275 b	12,845 b
		T2	412 a	2572 a	6766 a	12,772 a	14,544 a
	LAI	T1	0.61 a	1.51 b	2.46 b	3.20 b	2.62 b
		T2	0.50 b	1.65 a	2.91 a	3.86 a	3.14 a
	Shoot:root ratio	T1	4.56 a	12.64 a	13.99 a	22.53 b	28.35 b
		T2	2.92 b	9.85 b	12.62 a	26.55 a	33.59 a
2020	DM (kg/ha)	T1	542 a	2497 b	5927 b	10,615 b	12,091 b
		T2	506 a	2694 a	6690 a	12,160 a	13,833 a
	LAI	T1	0.87 a	1.56 b	2.58 b	3.26 b	2.53 b
		T2	0.74 b	1.70 a	3.01 a	3.92 a	3.03 a
	Shoot:root ratio	T1	5.26 a	12.96 a	15.89 a	25.78 b	29.56 b
		T2	3.52 b	10.56 b	16.45 a	29.86 a	33.88 a
2021	DM (kg/ha)	T1	490 a	2538 b	6208 b	12,302 b	13,162 b
		T2	462 a	2711 a	6947 a	13,943 a	14,891 a
	LAI	T1	0.68 a	1.65 b	2.59 b	3.36 b	2.78 b
		T2	0.57 b	1.82 a	3.09 a	4.07 a	3.36 a
	Shoot:root ratio	T1	7.34 a	14.77 a	16.44 a	23.53 b	32.54 b
		T2	4.03 b	13.36 a	16.62 a	26.58 a	36.65 a

Different letters after values indicate significant treatment effect (Tukey's test was used to detect significant differences)

Effect of Improved Irrigation on Potato Growth and Tuber Yield

In order to test the effect of the Improved Irrigation on potato growth, tuber yield, water productivity and nitrogen use efficiency, field experiments with two treatments (Conventional irrigation,T1; Improved irrigation, T2) were conducted in 2019–2021. At potato seedling stage, no differences were observed in plant dry matter accumulation (DM) under the two irrigation treatments; after tuber formation, plant DM and leaf area index (LAI) under T2 were both larger than those under T1, and the differences gradually increased. For instance, at tuber formation stage, the DM under T2 was 6% higher than that under T1, while at harvest, the increase was 13%. The results were similar for three years (Table 3).

Three years of results all showed that at early growth stage of potato, the shoot:root ratio under T2 was lower than that under T1; from tuber bulking stage, the ratio became gradually higher under T2 than that under T1 (Table 3).

Potato yields ranged from 47 to 56 Mg/ha. In 2019, the yield under T2 was 12.5% higher than that under T1; similarly, yield under T2 was 8.5% and 12% higher than that under T1 in 2020 and 2021, respectively. In addition, the percentage of marketable tuber under T2 was significantly higher than that under T1 for all 3 years (Table 4).

Table 4 Potato yield, water productivity (WP) and nitrogen use efficiency (PFP_N) under different irrigation strategies

Year	Treatment	Yield (Mg/ha)	Marketable tuber rate (%)	WP (kg/m^3)	PFP_N (kg/kg)
2019	T1	48 b	71.3 b	137.3 b	160.5 b
	T2	54 a	82.1 a	159.2 a	175.9 a
2020	T1	47 b	70.5 b	124.2 b	159.1 b
	T2	51 a	81.2 a	142.1 a	170.3 a
2021	T1	50 b	71.2 b	143.8 b	166.7 b
	T2	56 a	81.3 a	169.6 a	187.3 a

Different letters after values indicate significant treatment effect (Tukey's test was used to detect significant differences)

Table 5 Nitrogen uptake by potato plants (kg/ha) under different irrigation strategies and at different growth stages

Year	Treatment	Potato growth stages				
		Seedling	Tuber formation	Tuber bulking	Starch accumulation	At harvest
2019	T1	18.09 a	79.50 b	139.44 b	151.03 b	158.48 b
	T2	15.60 b	87.86 a	166.45 a	182.85 a	190.90 a
2020	T1	22.44 a	81.94 b	140.97 b	145.63 b	152.78 b
	T2	19.64 b	91.91 a	168.84 a	180.29 a	188.61 a
2021	T1	20.47 a	83.09 b	144.57 b	152.45 b	160.85 b
	T2	17.93 b	92.74 a	171.91 a	184.09 a	193.26 a

Different letters after values indicate significant treatment effect (Tukey's test was used to detect significant differences)

Effect of Improved Irrigation on Potato Water Productivity

Improved Irrigation (T2) significantly enhanced potato water productivity (Table 4). Compared to the conventional irrigation (T1), Improved Irrigation (T2) increased WP by 16% in 2019, 14% in 2020 and 18% in 2021.

Effect of Improved Irrigation on Potato N Uptake and N Use Efficiency

At seedling stage, total N uptake by potato plants under T2 was less than that under T1; after tuber formation, total N uptake under T2 began to be higher than that under T1, and the difference increased over time. For instance, at tuber formation stage in 2019, the N removal by potato plants per hectare under T2 was 10% higher than that under T1, while at starch accumulation, this number increased to 21% (Table 5).
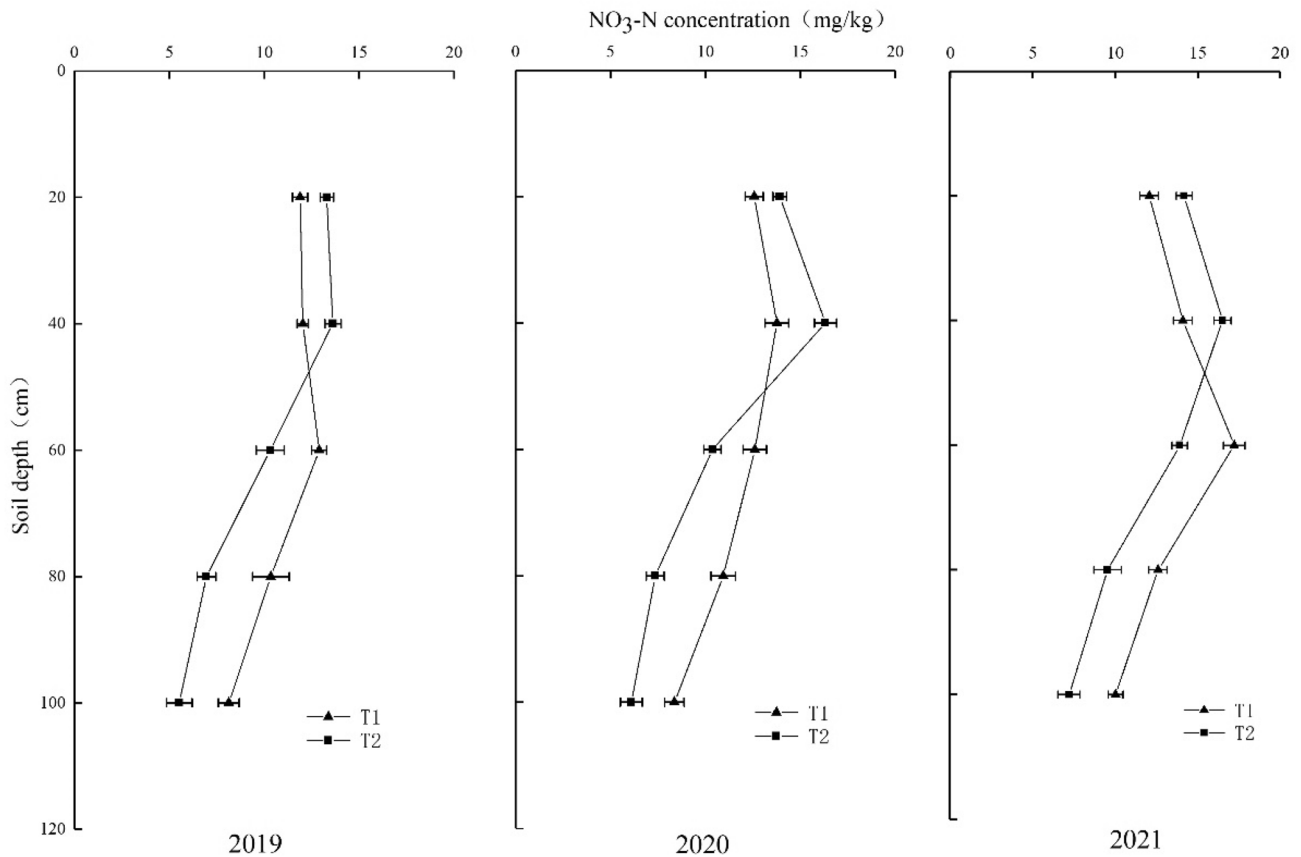
Fig. 2 Postharvest residual nitrate concentrations in the soil under two irrigation strategies

Potato nitrogen use efficiency is expressed as partial factor productivity of nitrogen fertilizer (PFP_N). Under treatment T2, the PFP_N was significantly higher than that under T1 across three years. In 2019, 15.4 kg more potatoes were produced per kg of N applied under T2 than under T1; 11.2 kg/kg N more potatoes under T2 in 2020, and 20.6 kg/kg N more potatoes under T2 in 2021 (Table 4).

After harvest, soil residual nitrate concentrations in 0–20 cm and 20–40 cm under T2 were 12–13% higher than those under T1, however in soil layer of 40–60 cm, they were lower under T2 than under T1, and in soil layers of 60–80 cm and 80–100 cm, they were much lower under T2 than under T1. Similar results were obtained in 2019, 2020 and 2021 (Fig. 2).

Discussion

Since water resources are very limited in Inner Mongolia, increasing water productivity in crop production is a critical goal. Changing flood irrigation in potato production into drip irrigation increased water productivity (Jia et al., 2018b), however it is still lower than those in some other countries, implying that the irrigation scheme still has great potential to improve. Knowledge of crop root distribution is a critical issue in water management and is especially important for potato production since it is a shallow-root crop with low water productivity and nutrient use efficiency (Alva et al., 2011; Fixen & Bruulsema, 2014; Iwama, 2008; Jia et al., 2018b). Potato root distribution in soil varies with soil and ecological conditions (Ahmadi et al., 2011; Hu et al., 2012; Lesczynski & Tanner, 1976), and this information is lacking in Inner Mongolia potato production region. In this study, potato rooting in this region was systematically observed. Results showed that potato roots penetrated deeper in the soil in Inner Mongolia than elsewhere (Ahmadi et al., 2008; Iwama, 2008; Munoz-Arboleda et al., 2006; Stalham & Allen, 2001), which could be related to soil texture (Qin et al., 2013). The results also indicated that potato root distribution in the soil at different growth stages varied greatly, with about 22% of roots distributed in 30–50 cm soil at tuber bulking stage, which was about twice that at tuber formation stage, while at the seedling stage, no root could reach the depth of 30–50 cm (Fig. 1). This provides critical information for improving the irrigation management. Until now, potato plants have been given 225 m^3/ha of water at each irrigation in local production, meaning that wet soil zone would be below 30 cm, however, more than 93% of potato roots at the seedling stage were distributed in 0–20 cm (Fig. 1), thus the water in soil deeper than 20 cm would be available to only a small fraction of the roots and become wasted. On the other hand, at tuber bulking stage, potato roots could reach 70 cm depth of soil layer, with 93–95% of roots distributed in 0–50 cm soil layer (Fig. 1), suggesting that an irrigation volume of 225 m^3/ha each time would not be enough to extend the wet soil zone to most of the rooting zone at this growth stage. Therefore, the current irrigation strategy for local potato production has great potential for improvement in view of potato root distribution in soil during plant growth.

Based on potato root distribution in the soil at different growth stages, we improved the conventional irrigation method used presently by most farmers. The improved method (T2) kept the total irrigation volume (1800 m^3/ha) unchanged, while adjusting the irrigation volume at each irrigation so that wet soil zone covers 80% of the roots (Table 2). The three years' results showed that potato yield under T2 was significantly higher than that under T1 (Table 4), suggesting that our optimized irrigation volume at each irrigation time based on potato rooting depth was efficient, and this is further supported by the results on water productivity showing 14–18% higher WP under T2 than under T1 (Table 4), therefore, this improved irrigation method can be adopted extensively in local potato production where there are similar soil texture and climates.

In Inner Mongolia potato production region, the soil texture is mainly sandy with low water holding capacity (Qin et al., 2013), and N leaching has always been the most important cause of low nitrogen use efficiency (Hu et al., 2012; Qin et al., 2013; Yang et al., 2018). Our results showed that residual N in deeper soil under T2 was much less than that under T1 although the same total amount of water was used in each (Table 2, Fig. 2), suggesting the improved irrigation (T2) can significantly decrease N leaching into deeper soil compared to conventional irrigation (T1). This may be due to several reasons: at seedling stage, potato roots were shallow and weak with lower absorption capacity, and with a large amount of fertilizer applied then, N leaching was prone to happen after irrigation, therefore, compared to T1, reduced irrigation (T2) at seedling stage would reduce the amount of N moving with water into deeper soil layer; Secondly, although the irrigation volume was gradually increased under T2 after tuber formation stage, and the N moving with water into deeper soil layer would increase, more root distribution in deeper soil at that stage (Fig. 1) would deplete more N there, leading to less N left in deeper soil. The results on potato nitrogen removal from soil (Table 5) confirmed this. Together with the results in Table 4 showing that partial factor productivity of nitrogen fertilizer (PFP_N) was significantly increased by T2, the irrigation improvement based on potato rooting pattern was shown to increase water productivity and N fertilizer use efficiency simultaneously. In addition, the results that more nitrogen remained in upper soil layer (0–50 cm) with less nitrogen left in deeper soil layer (50–100 cm) after harvest

under T2 (Fig. 2) are of significance beyond reducing environmental risk, considering that the residual N in the upper layer would be available to the succeeding crops following potato, therefore benefiting crop rotation system.

Conclusion

The changes observed in the rooting depth and root distribution of potato plants at different growth stages in Inner Mongolia suggest that the present irrigation strategy of uniform irrigation volume throughout local potato production is inefficient and has great potential for improvement.

Adjusting irrigation volume at each irrigation time to match the wet soil zone depth with 80% of root distribution during potato growth can significantly increase potato water productivity and decrease N leaching, leading to the promotion of potato growth with more N absorption, higher N use efficiency and increased potato yield.

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