Effects of water deficit in different growth stages and N fertilizer levels on maize growth and water use efficiency in Northwest China

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Abstract. Soil water and nutrients are key factors for plant growth and development as they are involved in many processes in plants. The purpose of this study was to investigate the effect of water deficit in different growth stages on maize growth and water use efficiency. Randomized block design with three replications and the treatments consisted of three levels of irrigation and three levels of N fertilizer were used. Three irrigation levels were W1 (water deficit at seedling stage), W2 (water deficit at jointing stage), W3 (water deficit at filling stage) and nitrogen (N) fertilizer levels were F1 (0.1 g pure N kg^{-1} soil), F2 (0.2 g pure N kg^{-1} soil) and F3 (0.3 g pure N kg^{-1} soil). The control treatment was composed of full irrigation and without N fertilizer application (CK). The results indicated that the interactions between irrigation and N fertilizer were important for shoot dry matter and root dry matter. The ranking of N fertilizer treatments, from high to low accumulations of root and stem-leaf dry matter averages, was F1>F3>F2. The falling of accumulation of nitrate in plants was mainly attributed to the proper enhancing ammonium reduced the adsorptive capacity of nitrate. Water deficit at different growth stages were significantly increase the total N content of stem-leaf. In conclusion, the maize can repair itself so they stop growing when water deficit at seedling stage, but do not die. They simply resume growth later when the water supply is plenty.

Introduction

In recent years, the effect of crop growth under the combination of regulated deficit irrigation and nitrogen has received scholars more attention. Agriculture consumes about 85% of the total fresh water used worldwide. While only 18% of the world's cultivated areas are devoted to irrigated agriculture. In agriculture, water and nitrogen are the main factors controlling plant growth. Irrigation and fertilizer application can overcome environmental factors effect [1-3]. The research found that water use efficiency of maize is increased by application of fertilizer [4]. The other reported that research the grain yield response and N-fertilizer recovery of maize under deficit irrigation and find that the range of grain yield reduction under deficit irrigation treatments, DI 50 and PRD 50, is 10-25% and significant ($P \leq 0.01$), compare to FULL irrigation practice [5]. N-uptake ability is reduced to about 20% of the well-watered control only when the soil water content is decreased to 5%.

N-uptake ability of roots maintained in very dry soil (5% soil water content) even for a prolonged period of 8 d, recover within 3 d following re-watering. Root growth increases one day after re-watering [6]. With increasing N rate the winter wheat yield and water use efficiency increased progressively, irrigation water regimes and N application also influences leaf area index and root growth, the yield of unfertilized wheat is relatively less affected by seasonal condition. Both N uptake and grain yield is increased linearly with increase in water use. The N use efficiency is maximum at 60 kg N ha-l, decreased at higher N levels irrespective of IR (irrigation regime) [7]. Most studies are on water use efficiency under deficit irrigation in the past. The study on fertilizer is mostly concentrated on water use efficiency under one fertilization condition in or abroad, or on efficient fertilizer use in certain irrigation conditions.

Thus, the present study was to focus on the relationships between the irrigation and N fertilizer input levels and maize growth and water use efficiency.

Materials and methods

The pot experiment carried out in rain shelter in at the Key Laboratory of Agricultural Soil and Water Conservation Engineering in Arid Areas, the Ministry of Education (34º20´N, 108º04´E and altitude 521 m), Shaanxi Province, and China. The topsoil is (20-40 cm) in the experiment station has a field capacity of 23-25% and heavy loam. The soil is air-dried by natural, grinded finely and over 5 mm sieve. The basic physical and chemical properties of soil is pH 8.14， organic matter 15.02 g kg^{-1}, total nitrogen 0.87 g kg^{-1}, total phosphorus 0.55 g kg^{-1}, total potash (K_2O） 16.8 g kg^{-1}, available nitrogen 78.32 mg kg^{-1}， available p 13.50 mg kg^{-1}. The maize breed (*Zea mays L.*, cv. 'Liyu 18') was sown on June 22nd, 2009, harvested on October 11th, duration of 108 days.

Randomized block design with three replications and the treatments consisted of three levels of irrigation and three levels of N fertilizer were used. Three irrigation levels were W1 (water deficit at seedling stage), W2 (water deficit at jointing stage), W3 (water deficit at filling stage) and nitrogen (N) fertilizer levels were F1 (0.1 g pure N kg^{-1} soil), F2 (0.2 g pure N kg^{-1} soil) and F3 (0.3 g pure N kg^{-1} soil).

Destructive samples are conducted at different growth stages, choose one representative plant from per pot, every treatment has 3 replications. Pick out complete root by washing method,rub root dry with absorbent paper, put into the oven after siding fresh weight, deactivate of enzymes for 0.5-2 h in 105 °C and heat to constant weight in 75-80 °C, then cool in a desiccators, weight dry matter with a electronic balance. At the same time, deactivation of enzymes and drying treatments are conducted on stems and leaves of maize plants.

Analysis of variance was conducted on root and shoot dry weight content and water use efficiency using a two-way analysis of variance (SAS GLM procedure version 9.2, SAS Institute Ltd., North Carolina, and USA). Duncan's multiple range tests were considered significant when $P < 0.05$.

Results

The effects of maize at dry weight water deficit and N fertilizer levels.

The root dry matter had a large increase with the advancement of growth stages under different nitrogen levels (Fig. 1). The cumulative amount from high to low is F1, F3, and F2, which had significant differences between different N levels under water deficit at seedling, jointing stages. Water deficit at seedling compared with full irrigation, the accumulation of root dry matter was reduced by 12.12%, 10.17%, and 11.11% respectively with F1, F3, and F2. The compensation effect was relatively significant after re-watering. There were significant differences between different N fertilizer levels. The accumulation of root dry matter had a very significant difference under water deficit at jointing. The result indicated that the F1, F3, and F2 level was reduced 22.22%, 22.47%, and 32.49%, respectively, compared with full irrigation. The recovery of root growth was small after re-watering. The roots dry weight was reduced 14.7%, 17.62%, and 16.67% respectively, compared with full irrigation under water deficit at filling stage. Compensation effect was not obvious with post re-watering, and significant difference between different N fertilizer levels. Water deficit at maturity had a significant impact on root growth and lower to full irrigation. Water and N fertilizer treatments had a very significant difference on the accumulation of root dry matter throughout the growth period. Water and N fertilizer combination had very significant difference under water deficit at jointing and filling stage.

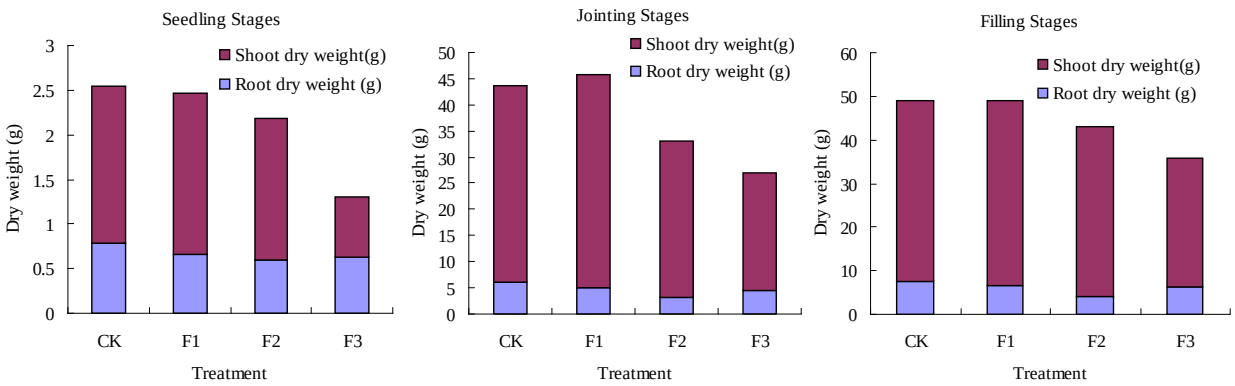

Fig. 1 Effects of water deficit in different growth stages and N fertilizer levels on maize dry weight

The effects of water use efficiency at water deficit and N fertilizer levels.

There was a significant effect of water deficit at any seedling, jointing and filling stage (Fig. 2). The interaction of water deficit and N fertilizer application had a significant effect on water use efficiency. Water use efficiency under water deficit at seedling was all higher than at other growth stages between different nitrogen levels. Water use efficiency was higher than water deficit at filling stage and lower than water deficit at jointing compared with CK. The reason might be the plant was small and demanded little water at seedling. The growth ability was weak at maturity. Water deficit at seedling and filling stage increased water use efficiency. N fertilizer application had no significant effect on water use efficiency. Absorbed nitrogen of crop could not been distinguished from original nitrogen in soil or applied nitrogen.

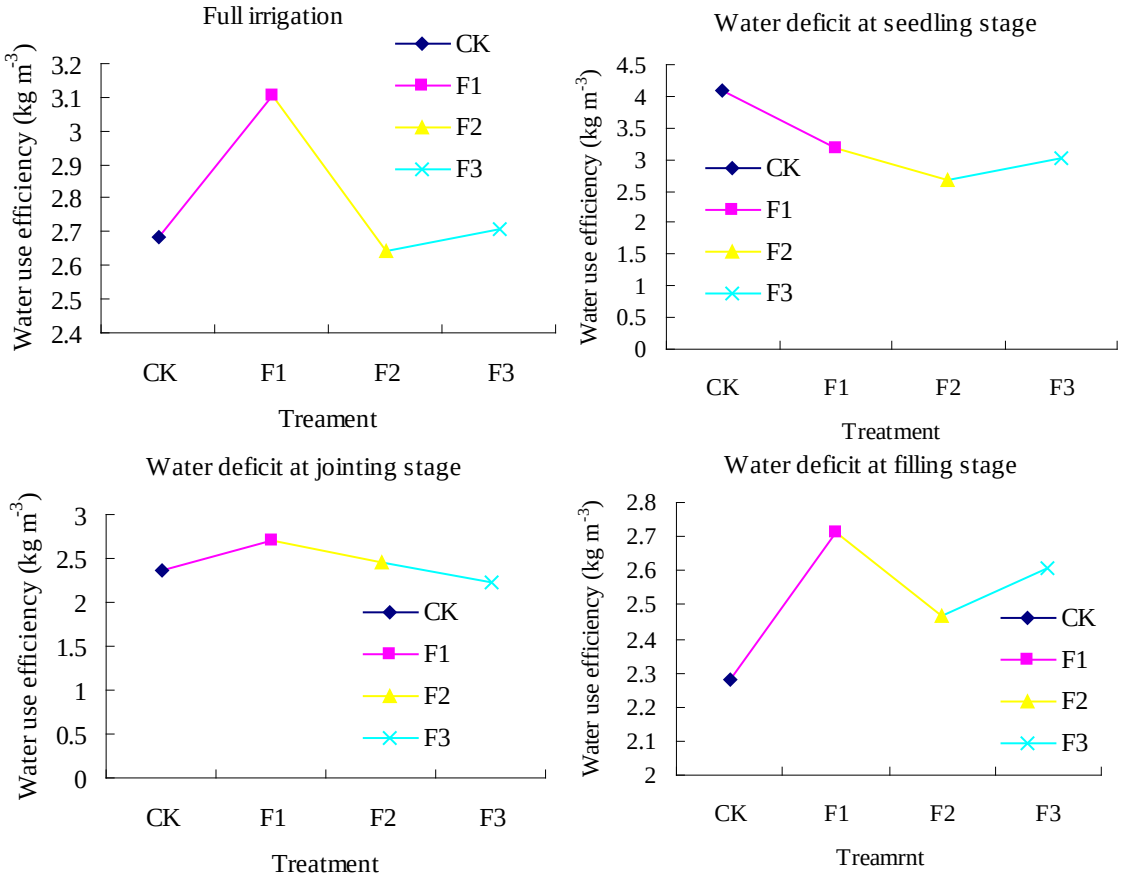

Fig. 2 Effects of water deficit in different growth stages and N fertilizer levels on water use efficiency

Discussion and conclusion

Nitrogen is an essential nutrient for plant growth, which promotes the growth of stem-leaf and improves the nutritional value of crops. Wang et al. (2008) studied and showed that moderate drought and proper nitrogen were conducive to height increase of stem. High and no nitrogen fertilizer were

useless for the height increase of stem [8]. The height of stem reduced as the increase of nitrogen at jointing. The influence on stem diameter, leaf width, stem-leaf dry weight and root dry weight of maize were consistent with on the height of stem. Shi et al. (2009) studied the effects of water deficit on dry matter accumulation, WUE and physiological indexes of maize and found that water stress significantly inhibited the growth of plants [9]. WUE declined by follow, and were all higher than CK after re-watering.

The results indicated that the interactions between irrigation and N fertilizer were important for shoot dry matter and root dry matter. The ranking of N fertilizer treatments, from high to low accumulations of root and stem-leaf dry matter averages, was F1>F3 >F2. The falling of accumulation of nitrate in plants was mainly attributed to the proper enhancing ammonium reduced the adsorptive capacity of nitrate. Water deficit at different growth stages were significantly increase the total N content of stem-leaf. In conclusion, the maize can repair itself so they stop growing when water deficit at seedling stage, but do not die. They simply resume growth later when the water supply is plenty.

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