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Full Length Research Paper

Water and nitrogen interactively increased the biomass production of Jerusalem artichoke (*Helianthus tuberosus* L.) in semi-arid area

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The response of height, aboveground and underground biomass of Jerusalem artichoke (*Helianthus tuberosus* L.) to water and nitrogen fertilization were studied in north-eastern Inner Mongolia, China. The results showed that water was a main limiting factor on the height and yield of Jerusalem artichoke; it significantly improved the height and yield of Jerusalem artichoke (including leaf, stem, root and tuber yields) (p<0.01). Nitrogen fertilizer significantly influence height and yield during irrigation and achieved higher yield during addition of nitrogen (25-50 kg ha^{-1}) (p<0.01). On the contrary, it was not significantly influenced without irrigation. By analyzing the correlation among tuber, leaf, stem and root, stem-leaf ratio, root-tuber ratio and root-shoot ratio under different condition (including irrigation and no irrigation), leaf size showed significant positive correlation with stem size and negative correlation with root-shoot ratio and root-shoot ration in two different conditions; during irrigation, leaf size indicated significant positive correlation with tuber size and the positive correlation between leaf and root size was not significant (p<0.01); without irrigation condition showed significant positive correlation between leaf and root size and the positive correlation between leaf and tuber size was not significant (p<0.01).

Key words: *Helianthus tuberosus* L., yield, height, irrigation, nitrogen addition.

INTRODUCTION

The environmental concerns about the negative effects of growing greenhouse gas emissions from fossil fuels and the growing global energy crisis call for renewable energy sources. Plant biomass feedstocks have been repeatedly identified as the sources of the renewable energy. Recently, Jerusalem artichoke (JA, *Helianthus tuberosus* L.) has attracted attention by the bioethanol industry sector because of its high productivity as well as high content of inulin. The inulin is present as a reserve carbohydrate in the tubers of JA and can be easily hydrolyzed for ethanol production (Maria et al., 2006; Mario et al., 2004; Toyohiko et al., 1996).

JA, a sunflower plant species originating from North America, is a C-3 warm-season crop characterized by high tolerances to drought and salinity. It has been introduced and naturalized as an economic crop worldwide, especially as forage and cover crops in margial lands, in temperate areas (Monti et al., 2005). The crop may be used to produce sugar and fructans, for various usages, such as food, chemical, electronic and pharmaceutical applications (Baba et al., 2006; Bosticco et al., 1989; Maijer and Mathijssen, 1991; Marchetti, 1993).

Studies on JA have mostly focused on industrial transformations of fructans, ethanol, inulin and so on (Marcel et al., 1996; Monti et al., 2005; Toyohiko et al., 1996) or crop clone precocity (Maria et al., 2006) while little is known about the effects of water and nitrogen on its biomass production.

JA is generally tolerant to drought but sensitive to excess water. Drought might dramatically decrease the

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yield of tuber especially at flowering stage or late tuber growth (Denoroy 1996). Effect of fertilizer on yield and height of JA was also significant. For example, lack of phosphorus or pottassium disturbs tuber morphogenesis, growth and yield, more than aerial growth (Soja et al., 1990). The yield response to nitrogen is stronger than to potassium because of the difference in their original content in the soil and because nitrogen determines potential photosynthesis and somewhat increases water use efficiency (Soja and Haunold, 1991).

There are some studies on the effect of water and nitrogen on JA, but these investigations only talk about the effect of water and nitrogen on weight of tubers or aboveground biomass (Long et al., 2008) and little talk about the effect of water and nitrogen on different organs of JA. The aim of this study was to investigate the effect of different degree of nitrogen addition, with or without irrigation on different organs (stem, root, leaf and tuber) and correlation among each others.

MATERIALS AND METHODS

Experimental design

The experiment site was located in Xilinhot (43°32′45″- 43°33′10″N, 116°40′30″- 116°40′50″E, 1200 m a.s.l), in north-eastern Inner Mongolia, China. The climate is a semiarid climate with mean annual temperature of 2.0°C and average annual precipitation of 350 mm falling mainly between June and September. The soil is sandy loam Chestnut soil in Chinese Soil Taxonomy.

The experiment with ten treatments, that is, N1 (without irrigation + without N[control]) , N2 (without irrigation + N [25 kg ha^{-1}]), N3 (without irrigation + N[50kg·ha^{-1}]), N4 (without irrigation + N [75 kg ha^{-1}]), N5 (without irrigation + N[100 kg ha^{-1}]), WN1(irrigation + without N), WN2 (irrigation + N [25 kg ha^{-1}]), WN3 (irrigation + N [50 kg ha^{-1}]), WN4 (irrigation + N [75 kg ha^{-1}]), WN5 (irrigation + N [100 kg ha^{-1}]), was carried out to study the effect of nitrogen addition on vegetative period (July 10) and irrigated one time every month (June 14, July 14, August 14 and September 14). Every treatment included five replicates. Planting takes place in spring (May 5 to 10) in bunch planting.

Planting depth is 30 to 35 cm, the row and plant spacing was 35 × 30 cm.

Field data collection

Ten plants were randomly selected for plant height measurements in each plot on September 27. On September 28, we randomly selected five plant samples in every plot, including aboveground and underground biomass. Aboveground biomass was cut from ground surface, and separated into leaf and stem. Underground biomass was taken from 0 to 30 cm depth, and separated into root and tuber. All of the plant samples were dried to constant weight under 75°C in oven and weighted.

Data analysis

Analysis of variance and correlation analyses were conducted using the general linear model (GLM) and correlation (CORR) and this was preceded by the SPSS17.0. All figures were ploted using SigmaPlot 10.0.

RESULTS

The effect of water and nitrogen on plant height

Compared with the control (N1), the water treatment significantly increased height but without irrigation, it does not have a significant effect on height (p<0.05). The order of height was WN3>WN4>WN2>WN5>WN1>N4>N1> N3>N2>N5. In these treatments, the height of WN3 was remarkably higher than other treatments (p<0.01) and there were no significant differences among WN4, WN2 and WN5. WN1 showed significantly lower height than WN3, WN4, WN2 and WN5, but it indicated remarkably higher height than N4, N1, N3, N2 and N5 (p<0.01). N2, N3 and N5 did not indicate remarkable different in height with N1 (control). N4 indicated significant difference in height with N1 (control) (p<0.01) (Figure 1). By analyzing variance of height (Table 1), it was showed that irrigation and N were significantly influenced on the height, and water is the maximum influencing factor on height.

The effect of irrigation and nitrogen on aboveground biomass

The aboveground biomass included leaf and stem. From Figure 2 (including A, B, C), we can seen that the effect of irrigation on fresh weight and dry weight of leaf, stem and aboveground biomass indicated similar trend, the yield during irrigation is remarkably higher than without irrigation (p<0.01).

To aboveground biomass weight (including fresh and dry weight), N indicated significant influence on weight during irrigation (p<0.01). On the contrary, the effect of nitrogen on yield was not significant (Figure 2A). The highest weight was obtained during WN2 (irrigation+N [50 kg ha^{-1}]), the yield in this condition was remarkably higher than in other treatments (p<0.01). From Figure 2B and C, the same trend was seen.

At the same time, we can see from Figure 2C that the fresh yield of stem was increased at first and then decreased with different amounts of nitrogen. On the contrary, the effect of nitrogen on leaf and aboveground biomass weight did not indicate significance.

Two-way ANOVA of weight of leaf, stem and aboveground biomass in different irrigation and nitrogen treatments (Table 2) revealed that nitrogen addition and irrigation significantly influenced yield (p<0.01). And the effect of nitrogen on leaf is higher than stem weight.

The effect of irrigation and nitrogen on underground biomass

From Figure 3, the yield of tuber, root and total underground biomass is significantly different between irrigation and without irrigation, and irrigation can

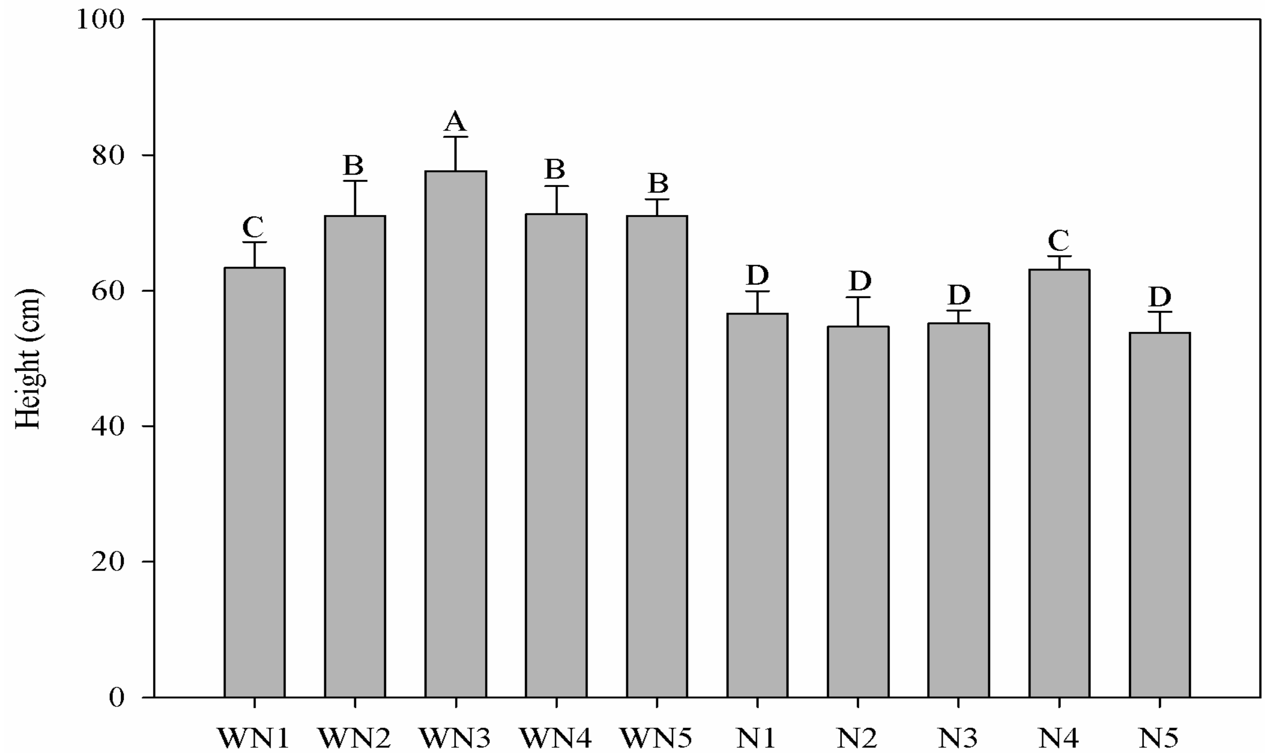

Figure 1. The height of Jerusalem artichoke (*Helianthus tuberosus* L.) under different treatment conditions. The uppercase letters indicate that there are significant different among floristic at the 0.05 level. (N1 (without irrigation + without N), N2 (without irrigation + N [25 kg ha^{-1}]),N3 (without irrigation + N[50 kg ha^{-1}]), N4 (without irrigation + N [75 kg ha^{-1}]), N5(without irrigation + N [100 kg ha^{-1}]),WN1 (irrigation +without N), WN2 (irrigation + N [25 kg ha^{-1}]), WN3 (irrigation + N [50 kg ha^{-1}]), WN4 (irrigation + N [75 kg ha^{-1}]), WN5 (irrigation + N [100 kg ha^{-1}]).

Table 1. Analysis of variance of height.

Parameter	DF	F value	*P*
Water	1	110.31	< 0.0001
Nitrogen	4	3.89	0.0093
Water*Nitrogen	4	4.77	0.0031

Table 2. Analysis of variance of aboveground biomass yield.

Parameter	DF	Leaf				Stem				Aboveground biomass			
		Fresh		Dry		Fresh		Dry		Fresh		Dry	
		F value	*P*	F value	*P*	F value	*P*	F value	*P*	F value	*P*	F value	*P*
Water	1	120.26	<0.0001	68.3	<0.0001	24.33	<0.0001	41.78	<0.0001	74.68	<0.0001	67.68	<0.0001
Nitrogen	4	4.25	0.0058	5.16	0.0019	2.55	0.0536	3.58	0.0138	2.73	0.0425	4.59	0.0038
Water*Nitrogen	4	1.9	0.1301	1.82	0.1436	3.24	0.0214	2.83	0.0369	2.63	0.0483	2.69	0.0448

significantly improve the yield (p<0.01). It showed the same trend on weight (root, tuber and total underground biomass) with different irrigation and nitrogen treatments. The order of weight is WN2>WN3>WN1>WN4>WN5> N3>N2>N4>N1>N5. The weight of WN2 is the highest and remarkably higher than other treatments (p<0.01). During irrigation, nitrogen significantly influenced yield. Without irrigation the influence of N was not significant.

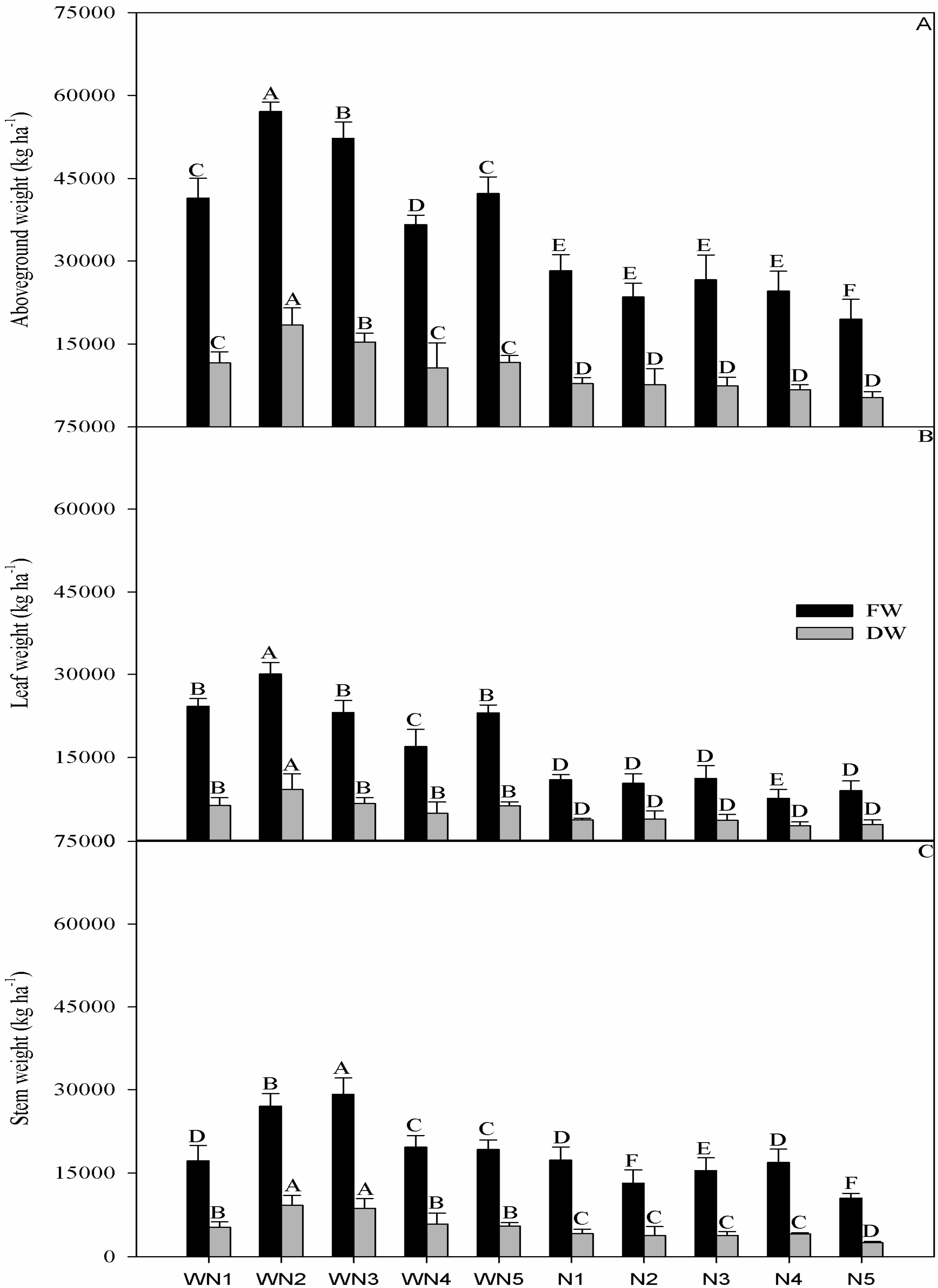

Figure 2. Aboveground biomass weight under different treatment conditions. The uppercase letters indicate that there are significant different among floristic at the 0.05 level. N1 (without irrigation + without N), N2 (without irrigation + N [25 kg ha^{-1}]), N3 (without irrigation + N [50 kg ha^{-1}]), N4 (without irrigation + N [75 kg ha^{-1}]), N5 (without irrigation + N [100 kg ha^{-1}]), WN1(irrigation + without N), WN2 (irrigation + N[25 kg ha^{-1}]), WN3 (irrigation + N [50 kg ha^{-1}]), WN4 (irrigation + N [75 kg ha^{-1}]), WN5 (irrigation + N[100 kg ha^{-1}])

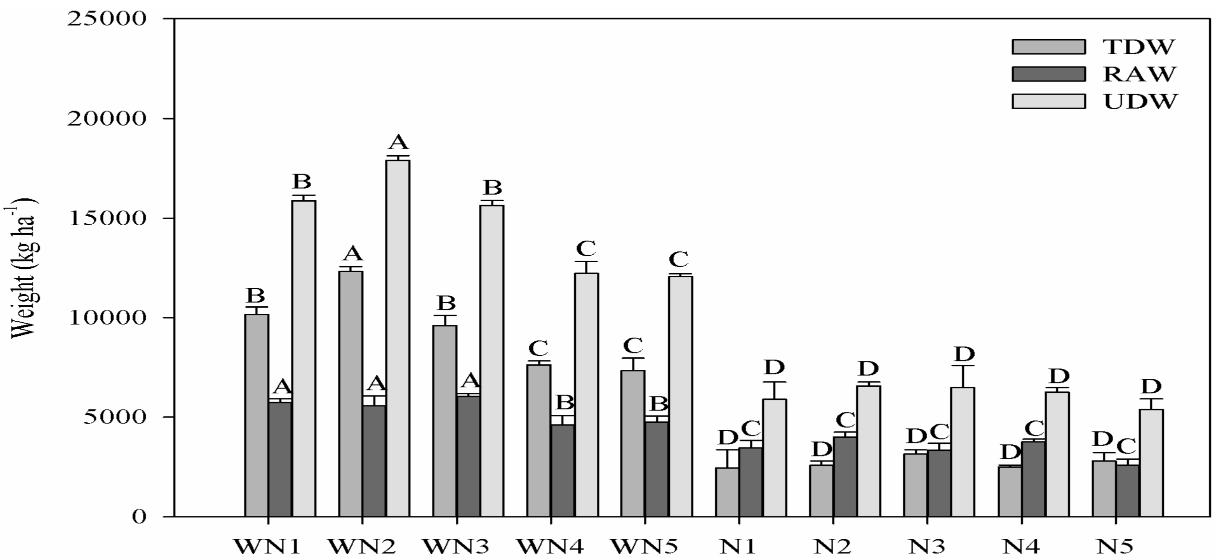

Figure 3. Underground biomass weight under different treatment conditions. The uppercase letters indicate that there are significant different among floristic at the 0.05 level. N1 (without irrigation + without N), N2 (without irrigation + N [25 kg ha^{-1}]), N3 (without irrigation + N [50 kg ha^{-1}]), N4 (without irrigation + N [75 kg ha^{-1}]), N5 (without irrigation + N [100 kg ha^{-1}]), WN1(irrigation + without N), WN2 (irrigation + N[25 kg ha^{-1}]), WN3 (irrigation + N [50 kg ha^{-1}]), WN4 (irrigation + N [75 kg ha^{-1}]), WN5 (irrigation + N[100 kg ha^{-1}]).

In Table 3, it showed that irrigation is the main influencing factor on weight of root and tuber. And the effect of nitrogen was remarkable on tuber; on the contrary it was not significant with root.

The correlation of stem, leaf, root and tuber

There are internal relations during growing of plant. So it is most important to study the correlation among plant organs to better understand their growth characters. So in this study, analysis of the correlation among tuber, leaf, stem, root, stem-leaf ratio, root-tuber ratio and root-shoot ratio in different condition (include irrigation and without irrigation) was carried out.

Leaf size showed a significant positive correlation with stem size and negative correlation with root-shoot ratio and root-shoot ration in the two different conditions, but there are differences in correlation between leaf and tuber, root size. During irrigation, leaf size indicated significant positive correlation with tuber size and the positive correlation between leaf and root size was not significant (p<0.01). On the contrary, the study showed a significant positive correlation between leaf and root size and the positive correlation between leaf and tuber size was not significant. There was different correlation between leaf size and stem-lead ratio. During irrigation the negative correlation is not significant, but without irrigation, the negative correlation is significant (p<0.01) (Table 4).

The correlations between stem and root size and tuber size, and stem-leaf ratio and root-shoot ratio showed same trend. It indicated significant positive correlation between stem and tuber size or stem-leaf ratio during irrigation, and the positive correlation was not significant without irrigation. There was same significant negative correlation between stem size and root-shoot ratio (Table 4).

During irrigation, the tuber size and stem-leaf ratio indicated negative correlation. On the contrary, the positive correlation was indicated between tuber size and stem-leaf ratio; at the same time, correlation between root-shoot ratio and stem-leaf ratio was negative during irrigation and positive without irrigation (Table 4).

DISCUSSION

Many crops are considered to be relatively resistant to drought, although, to achieve optimum growth or yield, sufficient water for irrigation is required (Denoroy, 1996; Mahouachi et al., 2006). In general, water stress will influence nutrient uptake by roots and transport from roots to shoots, due to restricted transpiration rates and mem-brane permeability (Erlandsson 1975). Water stress is one of the most important limitations to photosynthesis and then plant productivity (Boyer, 1982; Tezara, 2005). Certainly, JA was considered as more hardy against drought, but some studies have indicated it is sensitive to water stress. Under drought condition, the height, LAI and tuber weight will all be influenced (Denoroy, 1996). In this study, it is shown that water can influence growth of JA too. There were significant difference between irrigation and no irrigation. And the height and weight

Table 3. Analysis of variance of underground biomass yield.

Parameter	DF	Tuber fresh		Tuber dry		Root		Dry underground biomass	
		F value	*P*	F value	*P*	F value	*P*	F value	*P*
Water	1	208.45	<0.0001	221.88	<0.0001	35.59	<0.0001	176.01	<0.0001
Nitrogen	4	3.14	0.0246	4.03	0.0077	1.62	0.1878	3.85	0.0098
Water*Nitrogen	4	3.75	0.011	4.3	0.0055	1.01	0.4139	2.38	0.0679

Table 4. Correlation among different organs of Jerusalem artichoke (*Helianthus tuberosus* L.).

Organ	Leaf	Stem	Tuber	Root	Stem-leaf ratio	Root-shoot ratio
Irrigation						
Leaf	1					
Stem	0.624**	1				
Tuber	0.595**	0.460*	1			
Root	0.308	0.412*	0.464*	1		
Stem-Leaf ratio	-0.190	0.625**	-0.096	0.196	1	
root-shoot ratio	-0.556**	-0.612**	0.081	0.075	-0.277	1
Without irrigation						
Leaf	1					
Stem	0.565**	1				
Tuber	0.025	0.166	1			
Root	0.619**	0.846**	0.248	1		
Stem-Leaf ratio	-0.563**	0.318	0.110	0.170	1	
root-shoot ratio	-0.718**	-.470*	0.577**	-0.285	0.360	1

*Correlation is significant at the 0.01 level (2-tailed); *correlation is significant at the 0.05 level (2-tailed).

(including leaf, stem, root and tuber) can be significantly reduced without irrigation. So irrigation is necessary in Xilinhot to obtain optimum yield.

The effect of nitrogen nutrition was generally studied poorly. Researchers thought the yield response to nitrogen is nevertheless stronger than to phosphorus and potassium (Soja and Haunold, 1991), and high nitrogen fertilization will result in over consumption, excessive aerial growth and consequent decrease in harvest index and tuber yield. Certainly, crop still needs large amounts of fertilizer including nitrogen. In fact, to JA mild nutrient stress could improve yield which has been shown (Meijer 1993). In this study, it was showed that it is beneficial to height and weight of JA to add 50 - 75 kg nitrogen in every hectare. A significant influence was indicated under irrigation conditions, the effect was not significantly without irrigation.

By analyzing the correlation among different organs, correlations were indicated in two conditions (irrigation and no irrigation). It was shown that environment can influence the proportional composition of different organs. During irrigation, leaf size indicated significant positive correlation with tuber size, but no significant positive correlation was indicated between leaf and root sizes without irrigation. On the contrary, a significant positive correlation was indicated between leaf and root sizes, however, the correlation between leaf and tuber are not significant without irrigation. Reasons for these are: (1) LAI reduced by water stress to decrease of weight of leaf. (2) under water stress conditions, the root become longer in order to absorb water from depth soil to transport to leaf and stem. So the root biomass increased. The positive correlation between root and leaf sizes indicated significance. On the contrary, under irrigation the leaf and stem can obtain full water, these conditions improve photosynthesis and accumulation of matter to transport underground to grow the tuber. As a result, the correlation between tuber and leaf sizes indicated significant positive correlation.

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