Research Article

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Collaborative Influence of Elevated CO₂ Concentration and High Temperature on Potato Biomass Accumulation and Characteristics

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Abstract: An experiment with OTC (Open-top Chamber) was conducted to study the influence of elevated CO₂ concentration and high temperature on potato yields and quality, particularly the collaborative influence of these two factors on the accumulation of aboveground biomass (leaves, petiole, and stem), and underground biomass (root and tuber) in potato, and the influence on potato characteristics. The results showed that the accumulation of dry weight of potato stem and aboveground biomass under the combined treatment of elevated CO₂ concentration and high temperature (warming) was significantly higher than that of the control group by 35.8%-53.4% and significantly higher than that of the warming treatment group by 24.4%-34.4%. In terms of potato stem and aboveground biomass in the combined treatment group, the occurrence time of peak accumulation was postponed, but the accumulation velocity was increased; the interval days of fast biomass accumulation was prolonged than the warming treatment group and the control group. In this combined treatment experiments, the fresh weight accumulation of potato tuber was lower than the warming treatment group by 5% during the middle stage of tuber formation. But the fresh weight accumulation in the combined treatment was higher than the warming treatment group and the

control group during the rest stages of tuber formation: the tuber fresh weight in the mature stage was higher than the warming treatment group and control group by 24.1%, and 3.4%, respectively. In terms of tuber fresh weight in the combined treatment group, the occurrence time of peak accumulation was postponed; the interval days of fast accumulation was prolonged compare to the warming treatment, but close to the control group.

Keywords: climate change; CO₂ increase; combined treatment; biomass change; potato.

1 Introduction

Potato (*Solanum tuberosum* L.), the fourth major crop after rice, wheat and maize, is grown in 157 countries; the global planting area is 19,302,642 hm², and the total yield is 388,190,674 t. In China, the plantation area is 7,767,481 hm² and the yield is 99,205,580 tone as of 2017, which consists 25.6% of the global yield [1].

Temperature is one of the major climatic factors influencing potato growth and biomass accumulation [2]. The response of potato to temperature in different physiological stages varies a lot [3], as high temperature will influence the plant shape, anatomy, as well as physiological and biochemical changes, which further influences the crop growth, decreases the biomass accumulation, and reduces the economic yield [4]. A research study has revealed that the optimal ambient temperature for potato biomass accumulation is 20°C. Potato growth will accelerate but the crop growth cycle will shorten when the ambient temperature is 25-30°C. Because of shortened growth cycle, photosynthesis process is shortened as well. Due to this shortened photosynthesis, the dry matter distribution is changed, thus, the dry matter accumulated is reduced [5-7]. An evaluation of a potato growth model in combination with climate change revealed that the potato yield would be decreased by 18%-32% when the simulated air temperature is elevated

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by 2.1 - 3.2°C. However, adaptive measures including species seed selection, cropping system adjustment and planting structure change, etc. may be taken to reduce the adverse effect of climate change on cropping [8,9]. For example, the potato stomatal conductance, crop net carbon assimilation rate and biomass accumulation would be improved by supplying sufficient water and suitable temperature increasing with day and night temperature between at 20-30 °C [10].

During the whole growing cycle with elevated CO₂ concentration, crop assimilation efficiency increased, and the distribution of dry matter accumulation among organs changes. Dry matter accumulation in leaves decreased, while dry matter accumulation in tubers increased. When harvestable, total fresh weight of tubers increased and water utilization efficiency increased. Thus, elevated CO₂ concentration is conducive to the improvement of tuber crops such as potatoes [11-15]. When the CO₂ concentration was increased by 370 - 740 $\mu\text{mol}\cdot\text{mol}^{-1}$, the potato yield in the treatment zone was 27%-49% higher than that in the control [16]. In the combined treatment, when the CO₂ concentration was increased by 260-300 $\mu\text{mol}\cdot\text{mol}^{-1}$, along with the farming temperature rising by 1.5-2.5°C, the potato leaf net photosynthesis rate was higher than the control group. Under this collaborative influence, the net photosynthesis rate in major growing phase, which is from inflorescence formation stage to early tuber expansion stage, was 2.1 times higher than the control group. The water use efficiency was 76.8% higher than the control group. The aboveground biomass (fresh stem weight) was 40.6% higher than the control group. The actual yield was 12.9% higher than the control group [17]. But some negative effect of CO₂ concentration multiplying on the yield was found in the experiment [18]; the improved CO₂ supply can accelerate leaf aging and flowering period [17,19].

According to AR5 of IPCC, by following representative concentration pathways (RCP 4.5), i.e. it is assumed that human try to reduce the greenhouse emission, and the target radiative forcing is realized and stabilized at 4.5 W•m⁻² by the minimum cost, the equivalent CO₂ concentration will be stabilized at 650 $\mu\text{mol}\cdot\text{mol}^{-1}$ after 2100, and the global surface temperature increasing will be controlled within 2.0°C [20].

It is also estimated that the major potato planting regions at the middle latitude of planet will be influenced by temperature increasing in the future decades [21]. When temperature rising and CO₂ concentration increasing, how does the biomass in potato's nutritive organs change? What are the similarities and differences between aboveground biomass accumulation and

underground biomass accumulation? These questions require further study. Thus, taking an experiment to study the influence of CO₂ concentration increasing and temperature increasing on potato biomass accumulation and analyze their collaborative influence on the dynamic process and characteristic parameters of fresh dry weight accumulation of aboveground potato biomass (stem and leaf) and underground biomass (root and tuber) will build a scientific foundation for studying the influence of climate change on crops and provide references for the adaptation to climate change in semiarid regions.

2 Experimental design and methods

2.1 Experimental design

The experiment was carried out in Dingxi arid meteorology and ecological environment experimental base of Lanzhou Institute of Arid Meteorology, China Meteorological Administration during 2016-2017. The experiment was done in a new type octahedron OTC (Open-top Chamber) of 18 m² base area and 3 m height. The shape of OTC's cross section is octagon. Eight flanks are covered by transparent glass and top surface is opened. Free-air CO₂ Enrichment (FACE) is open to the environment, and there is no barrier around experimental site. When CO₂ gas is supplied, CO₂ tends to diffuse to surrounding area, which makes it difficult to control the CO₂ concentration at a higher consistent level than the control group's level. Thus, the CO₂ concentration control ability of OTC is better than FACE. As a result, OTC has been widely used as a CO₂ concentration multiplying simulation device in related fields at home and abroad.

Two treatments and one control were designed in the experiment: One treatment was conducted by increasing temperature (IT). A temperature monitor was used and the air temperature increasing was controlled at $2.0 \pm 0.5^\circ\text{C}$ (1.5-2.5°C); the other treatment was conducted by both increasing temperature (IT) and increasing CO₂ concentration (IC) (IT + IC). A CO₂ concentration monitor was used and the CO₂ concentration was controlled at $650 \pm 20 \mu\text{mol}/\text{mol}$; Control group was set in large farm as control check (CK), and the CO₂ concentration in natural air was about 370 $\mu\text{mol}/\text{mol}$. The area of each treatment was 18 m² in OTC and each treatment was repeated for three times. The experimental farm is flat with uniform fertility. Soil type is loessal soil with alkalescence. During the whole growing cycle, OTC structure, water, fertilizer

and field management measures were exactly the same, but the treatments (CO₂ and temperature) were different. Diseases and insects were controlled strictly.

The potato variety in the experiment was “New Daping”, which was widely planted in the experimental region. In 2016, potatoes were sown on April 29th and harvested on October 15th, with the row space of 40 cm, and the plant space of 45 cm. In 2017, potatoes were sown on April 29th and harvested on October 11th, with the row space of 45 cm, and the plant space of 50 cm. Tubers were divided into 4-5 pieces, according to positions of bud, and then planted. Each piece weighs about 30 g.

In elevated CO₂ concentration treatment, CO₂ was supplied continuously from seedling stage to harvestable stage; the CO₂ concentration was controlled by a CO₂ concentration monitor in the OTC, and CO₂ was supplemented between 07:00-19:00 every day.

2.2 Measured items and measuring methods

The growth period covers the sowing stage, seedling stage, branching stage, inflorescence formation stage, flowering stage and harvestable stage [22]. The plant height was observed for 5 continuous plants in each zone (OTC, CK) at the branching stage, inflorescence formation stage, flowering stage and harvestable stage. The density was observed in the branching stage and harvestable stage, and items measured were the width, row spaces, length, hole spaces and the number of plants [22].

The biomass and leaf area were measured respectively at the leaf, petiole, stem and tuber of two individual plants in each zone (OTC, CK) at the branching stage, inflorescence formation stage, flowering stage and harvestable stage. They were measured once per 5 and 10 days after the flowering stage. The biomass measurement included fresh weight measurement (tubers) and dry weight measurement (leaves, petiole, and stem). Fresh weight and dry weight per square meter, water content and growth rate were then calculated as well.

2.3 Data analysis

In each growth cycle, potato biomass is accumulated slowly at beginning, and quickly in a certain stage, and slowly afterwards till the growth is stopped, i.e. it is a dynamic growing process of “increasing rate of accumulation – quick accumulation – slow accumulation”. The accumulation process complies with the Logistic growing

curve [23], and can be simulated with Logistic growing curve equation.

The simulating equation for dry matter accumulation is:

$$y = \frac{k}{1 + e^{(a-bx)}}$$

Where, y is the dry matter; k is the ultimate growth amount under an infinite development time, a and b are regression coefficients, x is the development time, e is the base of the natural logarithm.

From the first derivative of the dry matter accumulation equation, the dry matter accumulation speed function can be obtained:

$$v = \frac{dy}{dx} = \frac{kbe^{a-bx}}{(1 + e^{a-bx})^2}$$

Where, v is the dry matter accumulation speed.

From the first derivative of the dry matter accumulation speed function, and letting $\frac{dv}{dx} = 0$, the peak dry matter accumulation time $T_{\max}$ and the peak dry matter accumulation speed $V_{\max}$ can be obtained.

From the second derivative of the dry matter accumulation speed function, the following can be obtained:

$$\frac{d^2v}{dx^2} = \frac{d^3y}{dx^3} = kb^3 e^{a-bx} \frac{1 - 4e^{a-bx} + e^{2a-2bx}}{(1 + e^{a-bx})^4}$$

Letting $\frac{d^2v}{dx^2} = 0$, i.e. $1 - 4e^{a-bx} + e^{2a-2bx} = 0$, the two characteristic points of the function can be obtained:

$$x_1 = \frac{a - \ln(2 + \sqrt{3})}{b}, \quad x_2 = \frac{a - \ln(2 - \sqrt{3})}{b}$$

Where, x_1 is the time when the dry matter is accumulated from a slow rate to a fast rate, and x_2 is the time when the dry matter is accumulated from a fast rate to a slow rate [24].

The data were processed with statistical test method, linear regression, non-linear regression and F-test. The significance level $P \leq 0.05$.

Ethical approval: The conducted research is not related to either human or animal use.

Table 1: Dynamic simulation and characteristic parameters of dry matter accumulation for potato leaf in different treatments.

Treatment	Dry matter accumulation model	First derivative	T_{max}/d	$V_{max}/g/(m^2 \cdot d)$	X_1/d	X_2/d	$(X_2 - X_1)/d$	F	P
IT	$y=105.101/(1+e^{2.602-0.0365x})$	$dy/dx=3.836 e^{2.602-0.0365x} / (1+e^{2.602-0.0365x})^2$	71	1.0	35	107	72	8.814	≤ 0.05
IT + IC	$y=155.12/(1+e^{4.48-0.052x})$	$dy/dx=8.066 e^{4.48-0.052x} / (1+e^{4.48-0.052x})^2$	86	2.9	61	112	51	22.839	≤ 0.01
CK	$y=115.21/(1+e^{3.42-0.0438x})$	$dy/dx=5.046 e^{3.42-0.0438x} / (1+e^{3.42-0.0438x})^2$	78	1.3	48	108	60	8.645	≤ 0.05

3 Result and analysis

3.1 Influence of CO₂ concentration increasing and temperature increasing on potato leaf dry matter accumulation

Fig 1 shows that from the potato seedling stage to the branching stage, the dry matter accumulation of leaves in IT is higher than CK by 14%-35.6% (averagely 24.6%), and it is even higher than IT + IC by 19.9%-46.2% (averagely 33.4%). The result of the experiment reveals that the potato leaf growth and the biomass accumulation were improved in the sowing stage, seedling stage and branching stage. From the inflorescence formation stage to harvestable stage, the dry matter accumulation of leaves in IT + IC is 11.8%-35.6% (averagely 29.9%) higher than CK, 11.9%-50.6% (averagely 41.3%) higher than in IT.

This result indicates that high temperatures can stimulate dry matter accumulation in leaves.

The peak time (T_{max}) of dry matter accumulation of leaves in IT + IC combined treatment was at the 86th day after sowing. T_{max} was respectively 15 days and 8 days later than IT and CK. The peak accumulation speed (V_{max}) was 2.9 g/(m²·d), respectively increased by 1.9 g/(m²·d) and 1.6 g/(m²·d). At the 61st day after sowing, the dry matter accumulation was transferred from slow process to quick process (x_1), which was postponed 26 days and 13 days respectively when compared to IT and CK. At the 112nd day after sowing, the dry matter accumulation was transferred from quick process to slow process (x_2), which was postponed by 5 days and 4 days respectively, when compared to IT and CK. The interval days of quick dry matter accumulation were 51 days, which is reduced by 21 days and 9 days respectively (Table 1).

For IT + IC treatment, the peak accumulation time is postponed; the peak accumulation speed is improved; the quick accumulation period is shortened.

Figure1: Dynamic simulation curve of dry matter accumulation for potato leaves in different treatments.

Figure 2: Dynamic simulation curve of dry matter accumulation for potato petiole in different treatments.

Table 2: Dynamic simulation and characteristic parameters of dry matter accumulation for potato petiole in different treatments.

Treatment	Dry matter accumulation model	First derivative	$T_{\max}/d$	$V_{\max}/g/(m^2 \cdot d)$	X_1/d	X_2/d	$(X_2 - X_1)/d$	F	P
IT	$y=27.429/(1+e^{2.867-0.0323x})$	$dy/dx=0.886 e^{2.867-0.0323x} / (1+e^{2.867-0.0323x})^2$	89	0.2	48	130	82	15.149	≤ 0.01
IT + IC	$y=61.162/(1+e^{4.304-0.0364x})$	$dy/dx=2.226 e^{4.304-0.0364x} / (1+e^{4.304-0.0364x})^2$	118	0.6	82	154	72	51.489	≤ 0.01
CK	$y=28.11/(1+e^{2.833-0.0267x})$	$dy/dx=0.751 e^{2.833-0.0267x} / (1+e^{2.833-0.0267x})^2$	106	0.2	57	155	98	16.250	≤ 0.01

3.2 Influence of CO₂ concentration increasing and temperature increasing on potato petiole dry matter accumulation

From the potato seedling stage to branching stage, the dry matter accumulation of petiole in IT was 15.8%-23.1% (averagely 19.6%) (Figure 2) higher than CK, 13.2%-27.1% (averagely 20.3%) higher than IT + IC. From the inflorescence formation stage to harvestable stage, the dry matter accumulation of petiole in IT + IC was 34.8%-122.2% (averagely 88.0%) higher than CK, 6.7%-104.7% (averagely 60.1%) higher than IT.

It reveals that from seedling stage to branching stage, potato petiole growth was accelerated in IT, and biomass accumulation was higher than CK and IT+IC. From inflorescence formation stage to harvestable stage, the dry matter accumulation of petiole in IT+IC was significantly higher than IT.

The peak petiole dry matter accumulation time in IT + IC was at the 118th day after sowing, respectively 29 days and 12 days later than IT and CK. The peak petiole dry matter accumulation speed was 0.6 g/(m²·d), which was 0.4 g/(m²·d) higher than IT and CK. The dry matter accumulation of petiole was transferred from slow process to quick process at the 82nd day after sowing, which was postponed by 34 days and 25 days respectively when compared to IT and CK. Then transferred from quick process to slow process at the 154th day after sowing, which was postponed by 24 days in comparison with IT but basically close to CK. The quick accumulation period of petiole dry matter was 72 days, which was reduced by 10 days and 26 days respectively (Table 2).

For the petiole under IT + IC treatment, the peak accumulation time was significantly postponed; the peak accumulation speed was improved; the quick accumulation period was shortened.

Figure 3: Dynamic simulation curve of dry matter accumulation for potato stem in different treatments.

3.3 Influence of CO₂ concentration increasing and temperature increasing on potato stem dry matter accumulation

The dynamic simulating curve (Figure 3) shows that the potato stem dry matter accumulation in IT + IC was 23.2%-61.8% (averagely 34.4%) higher than IT, 25.9%-105.5% (averagely 53.4%) higher than CK; from seedling stage to early tuber expansion stage in IT, the potato stem dry matter accumulation was 4.6%-27.7% (averagely 21.0%) higher than CK; in later tuber expansion stage, stem dry matter accumulation speed was decreased, which was 2.8%-5.8% (averagely 4.4%) lower than CK.

It indicates that the potato stem dry matter accumulation in IT + IC is higher than IT and CK.

The peak dry matter accumulation time for potato stem in IT + IC was at the 113rd day after sowing, 4 days later than IT and 2 days earlier than CK. The peak dry matter accumulation speed was 2.9 g/(m²·d), 0.6 g/(m²·d) and 0.5 g/(m²·d) respectively higher than IT and CK; the dry matter

Table 3: Dynamic simulation and characteristic parameters of dry matter accumulation for potato stem in different treatments.

Treatment	Dry matter accumulation model	First derivative	T_{max}/d	$V_{max}/g/(m^2 \cdot d)$	X_1/d	X_2/d	$(X_2 - X_1)/d$	F	P
IT	$y=146.43/(1+e^{6.87-0.0628x})$	$dy/dx=9.195 e^{6.87-0.0628x}/(1+e^{6.87-0.0628x})^2$	109	2.3	88	130	42	31.041	≤ 0.01
IT + IC	$y=199.59/(1+e^{6.455-0.0572x})$	$dy/dx=11.417 e^{6.455-0.0572x}/(1+e^{6.455-0.0572x})^2$	113	2.9	90	136	46	28.613	≤ 0.01
CK	$y=157.84/(1+e^{7.154-0.0620x})$	$dy/dx=9.786 e^{7.154-0.0620x}/(1+e^{7.154-0.0620x})^2$	115	2.4	94	137	43	62.575	≤ 0.01

accumulation in stem was transferred from slow process to quick process at the 90th day after sowing, 2 days later than IT and 4 days earlier than CK. Then transferred from quick process to slow process at the 136th day after sowing, 6 days later than IT and 1 day earlier than CK; the quick accumulation period of dry matter in stem was 46 days, 4 days longer than IT and 3 days longer than CK (Table 3).

For stem under IT + IC treatment, the peak accumulation speed was improved; the peak accumulation time was postponed compared to IT and advanced compared to CK; the quick accumulation period was prolonged in comparison with IT and CK.

3.4 Influence of CO₂ concentration increasing and temperature increasing on potato aboveground dry matter accumulation

The potato aboveground dry matter accumulation in IT + IC was 12.2%-42.2% (averagely 24.4%) higher than IT, and 23.4%-56.2% (averagely 35.8%) higher than CK. The potato aboveground dry matter accumulation in IT was 23.4%-56.2% (averagely 35.8%) higher than CK (Figure 4).

It reveals that from seedling stage to harvestable stage, the potato aboveground dry matter accumulation in IT + IC was averagely 24.4% and 35.8% higher than IT and CK respectively, while the accumulation in IT treatment is averagely 35.8% higher than CK.

The dynamic simulating curve (Table. 4) shows that the peak dry matter accumulation time for potato aboveground part in IT + IC was at the 105th day after sowing, 9 days and 8 days respectively later than IT and CK; the peak dry matter accumulation speed was 4.7 g/(m²·d), which was 1.3 g/(m²·d) and 1.1 g/(m²·d) higher than IT and CK, respectively. The aboveground dry matter accumulation was transferred from slow process to quick process at the 75th day after sowing, which was postponed by 7 days and 4 days compared to IT and CK, respectively. Then the aboveground dry matter accumulation was

Figure 4: Dynamic simulation curve of dry matter accumulation for potato aboveground part in different treatments.

transferred from quick process to slow process at the 134th day after sowing, which was postponed by 10 days and 12 days compared to IT and CK, respectively. The quick aboveground dry matter accumulation period was 59 days, 3 days longer than IT and 8 days longer than CK.

The peak dry matter accumulation speed for potato aboveground part in IC+IT was improved in comparison with IT and CK. The peak accumulation time was postponed in comparison with IT and CK. The quick accumulation period was prolonged than IT and CK.

3.5 Influence of CO₂ concentration increasing and temperature increasing on potato root dry matter accumulation

From potato sowing stage to branching stage, the dry matter accumulation for potato root in IT + IC was 1.3%-1.8% (averagely 1.7%) (Figure 5) lower than IT, 3.1%-17.7% and averagely 10.4% lower than CK; the dry matter

Table 4: Dynamic simulation and characteristic parameters of dry matter accumulation for potato aboveground part in different treatments.

Treatment	Dry matter accumulation model	First derivative	$T_{\max}/d$	$V_{\max}/g/(m^2 \cdot d)$	X_1/d	X_2/d	$(X_2 - X_1)/d$	F	P
IT	$y=287.23/(1+e^{4.538-0.0472x})$	$dy/dx=13.557 e^{4.538-0.0472x} / (1+e^{4.538-0.0472x})^2$	96	3.4	68	124	56	23.625	≤ 0.01
IT + IC	$y=419.56/(1+e^{4.704-0.0449x})$	$dy/dx=18.838 e^{4.704-0.0449x} / (1+e^{4.704-0.0449x})^2$	105	4.7	75	134	59	17.815	≤ 0.01
CK	$y=277.42/(1+e^{5.065-0.0525x})$	$dy/dx=14.565 e^{5.065-0.0525x} / (1+e^{5.065-0.0525x})^2$	97	3.6	71	122	51	67.468	≤ 0.01

Table 5: Dynamic simulation and characteristic parameters of dry matter accumulation for potato root in different treatments.

Treatment	Dry matter accumulation model	First derivative	$T_{\max}/d$	$V_{\max}/g/(m^2 \cdot d)$	X_1/d	X_2/d	$(X_2 - X_1)/d$	F	P
IT	$y=25.96/(1+e^{2.098-0.0279x})$	$dy/dx=0.724 e^{2.098-0.0279x} / (1+e^{2.098-0.0279x})^2$	75	0.18	28	122	94	16.246	≤ 0.01
IT + IC	$y=28.12/(1+e^{2.177-0.0266x})$	$dy/dx=0.748 e^{2.177-0.0266x} / (1+e^{2.177-0.0266x})^2$	82	0.19	32	131	99	18.367	≤ 0.01
CK	$y=19.36/(1+e^{1.034-0.0206x})$	$dy/dx=0.399 e^{1.034-0.0206x} / (1+e^{1.034-0.0206x})^2$	50	0.10	30	114	84	7.267	≤ 0.05

Figure 5: Dynamic simulation curve of dry matter accumulation for potato root in different treatments.

accumulation in IT was 1.42%-16.21% (averagely 8.8%) lower than CK. From inflorescence formation stage to harvestable stage, the dry matter accumulation in IT + IC was 0.97%-5.6% (averagely 3.4%) higher than IT, and 4.2%-43.2% (averagely 28.3%) higher than CK. The dry matter accumulation in IT was 5.6%-35.6% (averagely 25.4%) higher than CK.

From sowing stage to branching stage, the potato root dry matter accumulation in IT + IC was lower than IT and CK. From inflorescence formation stage to harvestable stage, the potato root dry matter accumulation in IT + IC was higher than IT and significantly higher than CK.

The peak time of dry matter accumulation for potato root in IT + IC is at the 82nd day after sowing, which was 7 days and 32 days later than IT and CK, respectively. While the peak speed of dry matter accumulation was 0.19 g/(m²·d), which was 0.01 g/(m²·d) and 0.09 g/(m²·d) higher than IT and CK, respectively. The dry matter accumulation in root was transferred from slow process to quick process at the 32nd day after sowing, which was 4 days and 2 days later than IT and CK, respectively. Then it was transferred from quick process to slow process at the 131st day after sowing, which was 9 days and 17 days later than IT and CK, respectively. The quick accumulation period of dry matter in root under IT + IC is 99 days, which was prolonged by 4 days and 15 days in comparison with IT and CK. (Table 5).

For root under IT + IC treatment, the peak accumulation time was postponed; the peak accumulation speed was improved; the quick accumulation period was prolonged.

Table 6: Dynamic simulation and characteristic parameters of fresh potato tuber in different treatments.

Treatment	Dry matter accumulation model	First derivative	T_{max}/d	$V_{max}/g/(m^2 \cdot d)$	X_1/d	X_2/d	$(X_2 - X_1)/d$	F	P
IT	$y=2375.25/(1+e^{14.959-0.1239x})$	$dy/dx=294.29 e^{14.959-0.1239x} / (1+ e^{14.959-0.1239x})^2$	121	73.6	110	131	21	222.299	≤ 0.01
IT + IC	$y=3081.56/(1+e^{10.165-0.0798x})$	$dy/dx=245.91 e^{10.165-0.0798x} / (1+ e^{10.165-0.0798x})$	127	61.5	111	144	33	52.579	≤ 0.01
CK	$y=2950.36/(1+e^{10.598-0.0838x})$	$dy/dx=247.24 e^{10.598-0.0838x} / (1+ e^{10.598-0.0838x})^2$	126	61.8	111	142	31	48.010	≤ 0.01

Figure 6: Dynamic simulation curve of fresh potato tuber in different treatments.

3.6 Influence of CO₂ concentration increasing and temperature increasing on potato tuber (fresh weight) accumulation

The fresh weight accumulation in potato tuber under IT + IC was 0.7%-25.0% (averagely 8.0%) higher than CK (Figure 6). In IT + IC, the fresh weight accumulation in potato tuber was different from IT at each growing stage. In the early stage of potato tuber accumulation, the fresh weight accumulation in IT is 8.8%-89.7% (averagely 58.5%) lower than IT + IC. In the middle stage, the fresh weight accumulation in IT was 1.7%-7.1% (averagely 4.4%) higher than IT + IC. In the late stage, the fresh weight accumulation in IT was 8.6%-19.4% (averagely 14.5%) lower than IT + IC.

The fresh weight accumulation of tuber in IT + IC was higher than CK. The fresh weight accumulation of tuber in IT + IC was lower than IT in the middle stage of tuber accumulation, but higher than IT in other stages of tuber accumulation.

The peak time for fresh weight accumulation of potato tuber in IT + IC was at the 127th day after sowing, which was

6 days later than IT and basically close to CK. While the peak speed of fresh weight accumulation for potato tuber was 61.5 g/(m²·d), which was 12.1g/(m²·d) lower than IT and basically close to CK. The fresh weight accumulation of tuber in IT + IC was transferred from slow process to quick process at the 111st day after sowing, which was close to IT and CK. Then it transferred from quick process to slow process at the 144th day after sowing, which was 13 days later than IT and basically close to CK. The quick fresh weight accumulation period of tuber was 33 days, which was prolonged by 12 days in comparison with IT and close to CK (Table 6).

For potato tuber under IT + IC treatment, the peak accumulation period was later than IT, and the quick accumulation period was longer than IT but close to CK.

4 Discussion

From the seedling stage to the branching stage, the ambient temperature is lower than the suitable threshold for potato growth, the leading factor determining the biomass accumulation is the air temperature. The biomass accumulation of potato leaves and petiole is promoted by single temperature increasing. Biomass accumulation speed is higher than CK and the combined IT+IC treatment. In inflorescence formation stage, with the enlargement of leaf area index, the temperature increasing effect is gradually reduced. The intercellular CO₂ concentration is increased by the combined IT+IC treatment [25]. This causes the sufficient material supply for potato leaf photosynthesis, and the net photosynthesis rate is improved as well [26]

As a result, the biomass accumulation on leaf and petiole is quickened and much larger than CK and IT. But the leaf aging in IT treatment is also quickened. The biomass accumulation is not only lower than combined IT+IC treatment, but also lower than CK [11,27].

From inflorescence formation stage to harvestable stage, the net photosynthesis rate was improved by the

combined treatment with elevated temperature and CO₂ concentration [17]; the biomass accumulation in the leaf and petiole is significantly improved. When the peak biomass and dry matter accumulation time are postponed, the peak accumulation speed is improved correspondingly. A slight increase in stage for accumulation in the leaf has significantly prolonged petiole, and the quick accumulation period is distinctly shortened.

The characteristic of biomass accumulation changes vary in potato stem, leaf and petiole. From seedling stage to harvestable stage, the potato stem dry matter accumulation under combined IT+IC treatment is averagely 34.4% and 21.0% higher than IT and CK, respectively. Due to the leading effect of stem biomass accumulation from seedling stage to harvestable stage, the biomass accumulation for potato aboveground part under the combined IT+IC treatment is higher than IT and CK [11-15].

The tuber accumulation under the combined IT+IC treatment is lower than IT only in middle stage but higher in other stages. The fresh weight accumulation of tuber under the combined IT+IC treatment is higher than CK. The accumulation in IT treatment is higher than CK only in middle stage but lower in other stages. Potato is suitable to grow in a cool condition. For IT treatment, ambient temperature increases above the suitable threshold temperature for potato growth in later tuber expansion stage, which will inhibit the tuber formation. On the other hand, elevated temperature and elevated CO₂ concentration simultaneously will promote the organic accumulation, which can accelerate the tuber expansion and improve the yield [9,16,17]. The increase of CO₂ concentration is beneficial to the improvement and production of potato and other tuber crops in the future, and is conducive to the improvement of crop water use efficiency [14, 21].

The experiment has clarified the main characteristics of the co-influence of elevated temperature and elevated CO₂ concentration on potato biomass, and created potato biomass accumulation models for different treatments. But it still need further study on impact and mechanism of future climate change [17, 29-30].

5 Conclusion

Elevated temperature can stimulate the accumulation of dry matter, accelerate the growth of leaf, and increase the accumulation of biomass. For the leaf and petiole treated by this combined treatment, the peak accumulation

time was postponed; the peak accumulation speed was improved; the quick accumulation period was shortened.

In the whole growth stages, the dry matter accumulation for potato stem and aboveground part in the combined IT+IC treatment is significantly higher than CK and IT. For potato stem and aboveground part with this combined treatment, in comparison with IT and CK, the peak dry matter accumulation is postponed; the peak accumulation speed is improved; the quick accumulation period is prolonged.

The tuber accumulation in the combined treatment group is lower than IT treatment only in middle stage but higher in other stages. The tuber fresh weight accumulation in the combined treatment group is higher than CK. In the combined treatment group, the peak accumulation time was postponed and the quick accumulation period was prolonged in comparison with IT treatment, but was close to CK.

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