Comparative Study on Different Planting Patterns in Cold-terra Japonica Rice Irrigated Areas

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Abstract. A weighing lysimeter is used to study the growth pattern and water consumption characteristics during the growth period of japonica rice with transplanting and direct-sowing planting patterns under controlled irrigation. By comparing yield components, yield and water productivity of japonica rice under different planting patterns, this paper clarifies the growth characteristics and water-consuming law during the growth period of japonica rice under different growing conditions, and contrasts the yield and water productivity of japonica rice with transplanting and direct-sowing planting patterns. The result shows: the tillering stage of japonica rice with direct-sowing planting lags behind that with the transplanting, but the growth compensation effect will be generated. Till the end of the growth period, the tillering and plant height between direct-sowing and transplanting are basically the same. In terms of grain yield, the two indicators including grain number per panicle and 1000-seed weight have a better performance in the YZ, the two indicators including effective panicles and maturing rate have a better performance in the SZB, and these four indicators are unfavorable in the HZB. However, transplanting has a distinct advantage in labor saving and mechanical aspects since it does not require rice seedling growing and transplanting, and rice does not require regreening.

1. Introduction
The water resource crisis is considered to be one of the most critical challenges facing the world in the future, and water resource shortage has already become a factor restricting the sustainable development of the society. Water conservation is not only a long-term strategy concerning the sustainable development of population, resources and the environment, but also an urgent mission for current economic and social development [1-2]. As an agricultural powerhouse, China has a huge consumption of water for agricultural use. In 2018, the national agricultural water consumption accounted for about 61.4% of the total water consumption in the society[3]. Developing water saving agriculture is the key to alleviating regional water resources shortage and ensuring the sustainable development of agriculture. Improving water use efficiency and productivity can solve the problem of water shortage for agricultural use effectively. In 2001, Document NO.1 of the Central Government specified that we shall implement strict management system of water resources and delimit "three red lines" of water resources, which puts forward more strict requirements for the amount of use, use efficiency and assimilative capacity of water resources.

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Heilongjiang province is a major province for paddy fields, and its japonica rice production accounts for more than a half of the national total. In 2018, the agricultural irrigation water consumption in Heilongjiang province accounted for 86.2% of the national total water consumption. Among them, water consumption of paddy fields accounted for 98.5% of the agricultural irrigation water consumption[4]. The huge irrigation water consumption of paddy fields and supply and demand contradiction of water resources have severely restricted the sustainable and healthy development of grain production in Heilongjiang province. How to minimize agricultural water consumption and ensure the sustainable development of agriculture while guaranteeing stable and high yield is a problem that needs to be solved urgently. Over the past 20 years, there have been many domestic and foreign research results on water demand variation law of water-saving irrigation in paddy fields, which successively shows the water demand variation laws in paddy fields under different water-saving irrigation conditions[5-7]. In the main rice production areas (under humid and subhumid climate conditions), currently the mainstream water-saving cultivation includes dry-wet alternate irrigation[8], dry farming cultivation[9], wet-shallow irrigation, controlled irrigation, intermittent irrigation[10], etc. These water-saving cultivation techniques reduce water consumption by focusing on evapotranspiration and seepage, so as to achieve the purpose of water conservation. The research suggests that the reasonable regulation of field water conditions is the basis for high and stable rice yields, and is of great significance for improving water resource use efficiency and reducing agricultural non-point source pollution[11-12].

This paper selected three irrigation techniques and two cultivation models applied in Heilongjiang province. With the use of the weighing lysimeter, it studied the growth pattern, water consumption characteristics and yield components change of japonica rice under different water-saving irrigation cultivation models, and clarified the growth characteristics and water consumption laws of japonica rice under different irrigation and cultivation models. It aims to provide references for water-saving cultivation of japonica rice, accelerate the development of water-saving and high-efficiency agriculture in the province, guarantee food security and water resources security and promote the sustainable development of agriculture.

2. Materials and Methods

2.1. Overview of the Experimental Area
The experimental area is located at Qing'an Irrigation Experimental Station in Heilongjiang province, which is 125°44′ east longitude and 45°63′ north latitude. The soil in the experimental station is the typical black soil in cold area, whose saturated moisture content is 49.18%, dry density 1.10 g/cm³, organic matter 4.96%, total nitrogen 15.06 g/kg, total phosphorus 15.23 g/kg, total potassium 20.11 g/kg, available nitrogen 198.29 mg/kg, available phosphorus 36.22 mg/kg, available potassium 112.06 mg/kg and pH 6.05. The annual average temperature is 2-3℃, the effective accumulated temperature above 10℃ varies between 2500℃ and 2800℃, and the solar radiation is 4000-4300MJ/(m²·a). For many years, the annual average precipitation is 500-600 mm, and the annual average water surface evaporation is 700-800 mm. The hydrothermal growth period of crops in this area is 156 to 171 days, with an average of 164 days, and the annual frost-free period is 128 days. The climate is cold-temperate continental monsoon. The experimental station is equipped with 24 weighing lysimeters with a diameter of 1.13 m and an area of 1 m², rain shelter facilities and underground corridors. Each set of weighing lysimeter is equipped with the automatic weighing device, with a maximum weighing of 6000 kg and discrimination weighing of 100 g.

2.2. Experimental Design
The experiment was carried out in a weighing lysimeter in 2014. It set up three japonica rice cultivation models including transplanting (YZ), direct sowing in paddy fields (SZB) and dry direct sowing (HZB). During the growth period, the water management adopted controlled irrigation mode,
which was repeated for three times for each setting. The moisture control indicators under different water-saving irrigation cultivation models are as shown in Table 1.

The experimental variety of japonica rice was Longqingdao No. 1, with a full growth period of 133 days. The direct sowing started on 17 May. The direct sowing in paddy fields adopted sowing in drill, with the row spacing of 30 cm, average 65 seeds/m, and 1 million basic seedlings/hm² after seedling emergence. Dry direct sowing adopted dibble sowing with the row spacing of 30 cm, the buried depth of 2 cm, and 1 million basic seedlings/hm² after seedling emergence. The seedlings were transplanted on 25 May, with an average of 5 seedlings/hole, and a density of 20 holes/m². On 16 September, the rice of all treatments was harvested to be measured. The amount of fertilizer applied in each plot was 110 kg/hm² for N fertilizer, 45 kg/hm² for P fertilizer, and 80 kg/hm² for K fertilizer. The fertilization ratio is base fertilizer: tillering fertilizer: flower-formation promoting fertilizer: flower keeping fertilizer = 4.5: 2.0: 1.5: 2.0. The management methods of pest control, weed clearing, etc. were the same as those of the local field.

Table 1 Moisture Control Indicators under Different Water-saving Irrigation and Cultivation Models

| Irrigation indicators | Regreening stage | Tillering stage | Jointing-booting stage | Heading-flowering stage | Milk ripe stage | Yellow ripening stage |
|-----------------------|------------------|-----------------|------------------------|-------------------------|-----------------|-----------------------|
| Irrigation upper limit/mm | 20               | 20              | 20                     | 0                       | 20              | 20                    |
| Irrigation lower limit/% | 80               | 85              | 85                     | 60                      | 85              | 85                    |
| Note: 1. Irrigation upper limit refers to the depth of field water, and the irrigation lower limit refers to the percentage of soil moisture content in the root layer to the saturated soil moisture content; 2. The depth of measuring the soil moisture content: 200 mm during regreening stage and tillering stage, 300 mm during jointing-booting stage, and 400 mm during heading-flowering stage, milk ripe stage and yellow ripening stage. |

2.3. Measurement Indicators and Methods

(1) Soil moisture/field water layer: the soil moisture was measured by the portable soil moisture meter, and the water layer was measured by water gauge every three days at 9 in the morning, and was also measured before and after irrigation each time.

(2) Water consumption: the reading of the weighing device was recorded at 9 every morning.

(3) Basic seedlings: After the japonica rice turned green, the basic seedlings were determined and the number of seedlings for direct sowing in paddy fields and dry direct sowing were determined.

(4) Tillering: 5 representative measuring points were selected and marked in each lysimeter, and would be measured every three days during tillering stage and every five days during other growth periods.

(5) Plant height: The fixed-point marking is the same as the tillering measurement. The plant height before heading is the height from the soil surface to the highest leaf apex of each hole, and the plant height after heading is the height from the soil surface to the highest spike top (not counting the awns).

(6) Yield monitoring of all varieties: all plants from each lysimeter were collected and the actual yields of the plot were determined.

3. Results and Analysis

3.1. Dynamic Change of Japonica Rice's Tillering and Plant Height under Different Cultivation Models

The division of growth period of japonica rice under different cultivation models is based on transplanting. The tillering stage of transplanting starts around 5 June and that of direct sowing starts around 14 June.
Figure 1 shows the dynamic change of tillering during japonica rice's growth period under different cultivation models with controlled irrigation. It can be seen from the figure that the tillering stage of direct sowing cultivation is about 10 days later than that of transplanting, but for that of direct sowing, once it starts to tiller, it directly enters the mid-stage of tillering during which the number of tillering increases rapidly. The number of tillers handled in the YZ was significantly higher than that of SZB and HZB from the early to mid-stage of tillering. The number of tillers handled in the SZB and YZ from the late stage of tillering to the yellow ripening stage differed slightly. The number of tillers handled in the HZB was lower than that of SZB and YZ from the late-stage of tillering to heading-flowering stage, and there is slighter differences from milk ripe stage to yellow ripening stage. The number of tillers handled in the YZ reaches the peak at the alternation of mid-stage and late-stage of tillering, and the number of tillers handled in the SZB and HZB reached the peak at the end of late-stage of tillering. In terms of tillering rate, the early-stage and mid-stage of tillering are the periods of rapid increase in the number of tillers handled. The increase rate of tillers in the YZ, SZB and HZB is 0.88 plants/(hole*day), 1.4 plants/(hole*day) and 1.14 plants/(hole*day) respectively. The tillering rate of direct sowing is significantly higher than that of transplanting, and the increase rate of tillers in the SZB is particularly remarkable. At the late-stage of tillering, the number of tillers handled in the YZ starts to decline gradually, and that in the SZB and HZB stabilizes. The number of tillers of all starts to drop during the jointing-booting stage and stabilizes during the milk ripe stage. The decrease rate of tillers in the YZ, SZB and HZB is 0.37 plants/(hole*day), 0.33 plants/(hole*day) and 0.29 plants/(hole*day) respectively from jointing-booting stage to heading-flowering stage, and that from milk ripe stage to yellow ripening stage is 0.08 plants/(hole*day), 0.04 plants/(hole*day) and 0.12 plants/(hole*day). There is a slight difference in the decrease rate of tillers between in the YZ and in the SZB. The decrease rate of tillers handled in the HZB is significantly higher than the other two models from milk ripe stage to yellow ripening stage. In terms of effective tillering rate, that of the YZ, SZB and HZB is 55%, 59.45% and 56.13% respectively, and that of direct sowing is higher than that of transplanting. From the analysis above, it can be concluded that for the direct sowing planting pattern, it lags behind the transplanting during the growth period, but after seedling emergence, it enters rapid tillering stage without regreening. At the late-stage of tillering, the number of tillers handled in the SZB is basically the same as that of the YZ. From heading-flowering stage to yellow ripening stage, the number of tillers handled in the SZB is slightly higher than that of the YZ, and the number of tillers handled in the HZB is lower than that of YZ and SZB. It indicates that under controlled irrigation conditions, the growth compensation effect is generated during the tillering stage in direct sowing planting, the number of tillers rises rapidly from mid-stage to late-stage of tillering, the effective tillers and effective tillering rate of SZB are slightly higher than that of YZ, and the growth compensation effect of HZB is lower than that of SZB.
Figure 2 shows the dynamic change of plant heights during japonica rice's growth period under different planting patterns with controlled irrigation. It can be seen from the figure that the plant height of transplanting pattern is higher than that of direct sowing planting pattern from tillering stage to heading-flowering stage, the rice grows slowly during mid-stage of tillering and grows rapidly from late-stage of tillering to heading-flowering stage in the direct sowing planting model, and the height of the rice handled in the SZB is basically the same as that of the YZ from milk ripe stage to yellow ripening stage while that of the HZB is slightly lower. The plant height handle in the SZB and that in the HZB differs slightly presenting consistent growth trends. In terms of plant height growth rate, that of YZ, SZB and HZB is 1.30 cm/day, 0.84 cm/day and 0.74 cm/day respectively, that of dry direct sowing is 0.50 cm/day, and that of YZ is substantially higher than that of SZB and HZB. From jointing-booting stage to heading-flowering stage, the plant height growth rate handle in the YZ, SZB and HZB is 1.04 cm/day, 1.46 cm/day and 1.56 cm/day respectively, and the plant height handled in the SZB and HZB grows rapidly during this stage. From milk ripe stage to yellow ripening stage, the plant height growth rate handle in the YZ, SZB and HZB is 0.59 cm/day, 0.56 cm/day and 0.55 cm/day respectively, with the plant height growth rate of three models basically the same, and the plant height stable. The above analysis shows that the plant height of direct sowing is lower that of transplanting during the early stage of the growth period, at the late-stage of tillering, the plant height grows rapidly, and at the end of the growth period, the plant height handled in the SZB is basically the same as that of transplanting with that of the HZB slightly lower.

3.2. Analysis of Japonica Rice's Water Consumption Stages under Different Cultivation Models

Figure 3 shows the change of evapotranspiration (ET) during japonica rice's growth period under different planting patterns with controlled irrigation. From the regreening stage to the early-stage of tillering, the field surface handled in the YZ is in the circulation of "shallow-wet-dry", that of the HZB and SZB is in the seedling stage, as there is no water layer on the field, ET handled in the YZ is higher than that of HZB and SZB, and the average ET handled in the YZ, HZB and SZB is 3.69 mm/d, 2.50 mm/d and 2.72 mm/d respectively. At the mid-stage and late-stage of tillering, the rice handled in the HZB and SZB enters the rapid tillering stage, with ET a little higher. At the mid-stage and late-stage of tillering, the average ET handled in the YZ, HZB and SZB is 3.57 mm/d, 2.95 mm/d and 3.11 mm/d respectively. From jointing-booting stage to heading-flowering stage, japonica rice's ET handled in three models reaches the peak. During the jointing-booting stage, the average ET handled in the YZ, HZB and SZB is 3.69 mm/d, 4.98 mm/d and 5.61 mm/d respectively, that of HZB and SZB starts to show growth compensation effect with ET rises quickly and higher than that of the YZ, and ET handled in the SZB is higher than that of HZB. During the heading-flowering stage, the average ET handled in the YZ, HZB and SZB is 5.64 mm/d, 4.98 mm/d and 5.61 mm/d respectively. Compared
with the jointing-booting stage, the average ET handled in the YZ stays stable and is slightly up, that of the SZB slightly dips and that of the HZB sharply decreases showing lack of growth potential. During the milk ripe stage, the average ET decreases in general, the average ET handled in the YZ, HZB and SZB is 3.81 mm/d, 4.05 mm/d and 4.11 mm/d, that of the YZ declines significantly, and that of the HZB and SZB is higher than that of the YZ. During the early yellow ripening stage, the average ET of japonica rice handled in the YZ, HZB and SZB is 3.56 mm/d, 3.97 mm/d and 3.99 mm/d, which is slightly lower than those during the milk ripe stage, and the average ET handled in the HZB and SZB is higher than that of the YZ. At the end of August during the late yellow ripening stage, the ET of all approaches zero. Through the above analysis, it can be concluded that the soil evaporation in the YZ during regreening stage is large, while that of HZB and SZB is smaller since there is basically no water layer at the seedling stage. From jointing-booting stage to heading-flowering stage, the average ET handled in the YZ and SZB stays high and stable, and that of the HZB drops considerably, which is not conducive to the yield formation. From milk ripe stage to early yellow ripening stage, the average ET of transplanting and direct sowing planting both starts to decline, but that of the direct sowing planting is higher than that of transplanting, showing a growth compensation effect. The water consumption of the YZ, HZB and SZB during the growth period is 388.62 m3/mu, 367.49 m3/mu and 306.55 m3/mu respectively. The water consumption of transplanting is the highest while that of the dry direct sowing is the lowest because HZB does not require soil preparation with water.

3.3. Analysis of Japonica Rice’s Yields and Components under Different Planting Patterns

Figure 4 shows the yield components index of japonica rice. It can be seen from the figure that, in terms of effective panicles, the amount is SZB > YZ > HZB, which is consistent with that of effective tillering. In terms of grain number per panicle, it is YZ > SZB > HZB, that of the SZB and HZB is 4.63% and 9.65% lower than that of the YZ respectively. In terms of 1000-seed weight, that of YZ is higher than that of SZB and HZB, there is a slight difference between that of SZB and that of HZB, and that of SZB and HZB is 12.50% and 13.85% lower than that of the YZ respectively. In terms of maturing rate, that of the SZB is the highest and there is a slight difference between that of the YZ and that of the HZB. From the four yield components indexes, it can be seen that the two indicators including grain number per panicle and 1000-seed weight are better in the YZ, the two indicators including effective panicles and maturation rate are better in the SZB, but in a slight way, and the four indicators of HZB are not competitive. Figure 5 shows the theoretical yield of japonica rice under different planting models. It can be seen from the figure that the theoretical yield is YZ > SZB > HZB, and the theoretical yield of SZB and HZB is 12.35% and 28.53% lower than that of the YZ respectively. Figure 6 shows the water productivity of japonica rice under different planting models. It can be seen from the figure that water productivity is YZ > SZB > HZB, and water productivity of SZB and HZB is 7.31% and 9.39% lower than that of the YZ respectively. Although the direct sowing is more water-saving than transplanting, its yields are much lower, so it has no advantage in water productivity. But for transplanting, it does not require seedling raising or transplanting, and the rice does not need to be regreened, which has obvious advantages in labor saving and mechanical aspects.
Figure 5 Yield of Japonica Rice under Different Planting Models

Figure 6 Water Productivity of Japonica Rice under Different Planting Models

4. Conclusion
Under controlled irrigation conditions, for direct sowing planting, the growth compensation effect is generated during the tillering stage, the tillers increase rapidly during the mid-stage and late-stage of tillering, and its peak time of tillering lags a little behind that of transplanting. The peak of tillering and effective tillers of the SZB is basically the same as that of the YZ. For HZB, its growth compensation effect is lower than that of SZB, and the peak of tillering and effective panicles are both lower than that of YZ and SZB. In terms of plant height, it grows slowly at the early stage of growth period in direct sowing, but at the late stage of growth period, there is no significant difference in plant height between direct sowing and YZ. The soil evaporation in the YZ during regreening stage is large, the soil evaporation is reduced in the direct sowing, and the growth compensation effect is generated during the late growth period in direct sowing. In terms of grain yield, the two indicators including grain number per panicle and 1000-seed weight have a better performance in the YZ, the two indicators including effective panicles and maturing rate have a better performance in the SZB, and these four indicators are unfavorable in the HZB. The theoretical yield of SZB and HZB is 12.35% and 28.53% lower than that of the YZ respectively, and the water productivity of SZB and HZB is 7.31% and 9.39% lower than that of the YZ respectively. However, transplanting has a distinct advantage in labor saving and mechanical aspects since it does not require rice seedling growing and transplanting, and rice does not require regreening.

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