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Effects of Drip Irrigation on Water Saving, Fertilization and Gas Emission in Arid Regions

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ABSTRACT

Drip irrigation under membrane is a new agricultural technology that can achieve high yield and high efficiency. Through research, it can give full play to its potential of increasing yield and increasing efficiency in current practical production. This paper analysed and summarized the yield limiting factors in current drip irrigation production by studying the yield potential and yield difference. Through model simulation and field experiments, the high-yielding and high-efficiency crop system was designed and verified. The effects of film mulching on greenhouse gas emissions were studied in a small ecosystem. Based on the experimental results show that nitrogen requirement for target yield and the regularity of nitrogen requirement of high-yielding maize optimized nitrogen management compared with farmers 80 kg/ha nitrogen management to reduce nitrogen input, from 350 kg/ha down to about 270 kg/ha output from 11.7 Mg/ha increased to 13.8 Mg/ha, nitrogen partial productivity increased to 51.0 from 33.3 kg/kg, while apparent nitrogen loss decreased to 64.5 from 171.5 kg/ha, showed that optimized nitrogen management is feasible in practice. Mulching can reduce the ecological respiration rate; nitrogen fertilizer can promote the ecological respiration rate.

INTRODUCTION

Fertilizer is the material basis of grain production and plays a vital role in ensuring food security. A large number of studies have shown that the application of chemical fertilizers can significantly increase grain yield by 40-50%. However, in recent years, although fertilizer input is still growing rapidly, the rate of food production is gradually slowing down (Gao et al. 2017). For example, from 1996 to 2005, China's fertilizer input increased by 51%, but the corresponding grain output only increased by 10%. At the same time, excessive application of fertilizers has caused many environmental problems, such as soil acidification, water eutrophication, air pollution and so on. To ensure food security and reduce environmental damage at the same time has become an inevitable demand for China's future sustainable agricultural development, and scientific fertilization is one of the important measures to simultaneously improve crop yield and fertilizer utilization rate. Agricultural soil, in the release of CO_2, CH_4 and N_2O, is an important source of greenhouse gases produced by human activities (Mosier et al. 2005). The form such as CO_2 and CH_4 emissions of greenhouse gases in the agricultural greenhouse gas emissions has a dominant position, according to the statistics 20% agricultural source of CO_2 from the atmosphere and CH_4 emissions by sources of agriculture respectively, accounted for about 50% of the emissions from human activity (IPCC 2007). Therefore, improving farmland carbon sink, improving farmland soil properties and reducing greenhouse gas emissions play an extremely important role in alleviating global warming. It has been found that mulch drip irrigation is an effective way to solve these problems.

PAST STUDIES

Since China introduced drip irrigation technology from foreign countries in the 1970s, it was first widely used in northwest arid areas such as Xinjiang and Gansu. After a period of time, drip irrigation under film developed rapidly in greenhouse vegetables. A study showed that drip irrigation under film significantly improved the yield and water use efficiency of greenhouse cucumber compared with traditional irrigation (Han & Zhou 2018). A recent research showed that, compared with the traditional farming model, submulch drip irrigation promoted the nitrogen absorption of plants and increased the dry matter yield (Kiani et al. 2016). Drip irrigation under film increased the utilization rate of nitrogen fertilizer and the yield of smart grains (Tao & Zhang 2017). A study compared the CH_4 emission difference between conventional irrigation and shallow-light water-saving irrigation and found that shallow-light water-saving irrigation could effectively inhibit CH_4 emission, especially the CH_4 emission peak at the later growth stage of rice, so that the emissions of early rice and late rice were significantly lower than the control, and the emission reduction range of late rice was larger (Wang et al. 2018a).

The innovation of this paper is to design and test the high-yielding and high-efficiency film drip irrigation system. Compared with the traditional high-yielding system, under the condition of maintaining the high-yielding level, the input of fertilizer and irrigation is greatly reduced, which has better environmental benefits. The above high yield system was verified and adjusted in the field from the aspects of nitrogen fertilizer management and fertilization times, and the comprehensive management system of submulch drip 2 irrigation in arid areas was finally established. Soil CH_4 emissions of each treatment in the two-year growth season were regularly observed by the static-black box method, and the seasonal and annual changes of soil CH_4 emissions of each treatment were analysed. The annual cumulative emissions of CH_4 in each treatment were estimated, and the effects of mulching and fertilization on CH_4 were analysed and compared.

SYSTEM DESIGN METHOD

Effects of Drip Irrigation on Maize yield Difference

***Study area overview*:** Generally speaking, China's corn production areas can be divided into four regions, of which the corn sown area in the main corn producing areas in northeast China is 10.3 million hectares, with a total yield of 581 million tons. Northeast corn production area is mainly located in Beishen 40 degrees W North. The region belongs to the cold temperate zone, humid, semi-humid stream climate, low temperature in winter and short frost-free period. 72 weather stations in the region from 1970 to 2009 data show that the average temperature of 4.9°C, the highest 11.1°C, lowest 0.5°C. The average annual rainfall in the region is 4mm, %60 concentrated in June to September. Because early frost often occurs in late September and early October, corn is usually planted in the spring (April to May). In recent years, drip irrigation under membrane has developed rapidly in this area.

***The data source*:** The model needs to input meteorological data, mainly including solar radiation, maximum and minimum temperature (Wang et al. 2018b). In order to simulate effectively, the model also needs accurate planting and harvest dates of crops, as well as the density. In this study, 14 experimental sites, easy to achieve high yield of maize, were selected in the northeast spring maize production area. Solar radiation, highs and lows come from weather stations near each point. Sowing and harvesting times and densities were derived from plot data in the literature, and the missing data were consulted with local agronomists. In order to understand the yield potential of drip irrigation under mulch in northeast spring maize, this study selected the model-based yield difference calculation method. The specific calculation method is as follows: model-based yield difference = simulated yield potential - average yield of farmers (Wu et al. 2017).

Design of Optimal Nitrogen Management for Drip Irrigation Maize under Membrane

***Study area profile*:** Field trials were conducted in Ganan county, Jilin province from 2014 to 2015. The soil type is pennaceous calcium black soil with pH of 7.9, organic matter content of 18.2 g/kg, total nitrogen of 1.32 g/kg and total scale of 0.49 g/kg. The climate of this region belongs to temperate continental monsoon climate, cold in winter and hot in summer. Corn in this area is planted in April and ripens in early October. The annual average temperature of corn growing season in this region is 16.2-20.9°C, and the average annual rainfall is about 320mm. More than 70% of the rainfall is concentrated in the corn growing season from May to September. The rainfall, average temperature and average sunshine in the test year (2014-2015) are shown in Fig.1.

This experiment is a completely randomized block group experiment, with 6 treatments: (1) control treatment without nitrogen fertilizer (CK); (2) optimize nitrogen application (ONR), and determine the total amount of nitrogen fertilizer and the proportion of each use according to the target yield and the nitrogen fertilizer demand rule in each key growth period; (3) nitrogen application was optimized and up-regulated; (4) nitrogen application was optimized and down-regulated; (5) optimize and increase nitrogen application; (6) traditional fertilization treatment for farmers. Based on the investigation of local farmers, 350kg/ha of nitrogen fertilizer was applied once before sowing. Each treatment is set to be repeated for three times, and the residential area is $300m^2$. The maize variety is Limin Qiao with planting density of 85,000 plants per hectare. In the experiment, 30% was used as the base fertilizer and the rest 70% was used as the top fertilizer. Nitrogen fertilizer was applied six times, before sowing, six leaf stage, ten leaf stage, silking stage, ten days after silking stage and milk ripening stage. The optimal nitrogen fertilizer amount was determined according to the nitrogen absorption amount in the six growing stages of maize. In this study, the theoretical nitrogen demand for yield potential 115.7 Mg/ha was 273 kg/ha. Therefore, the total amount of nitrogen fertilizer controlled in this experiment was 270 kg/ha. In 2014 and 2015, the nitrogen fertilizer with optimized nitrogen application was divided into 6 times for application, and 81, 27, 54, 54, 27 and 27 kg/ha were applied in pre-sowing, six leaf stage, ten leaf stage, silking stage, 10 days after silking stage and milk ripening stage. The fertilization time of the optimized up-regulation and down-regulation treatment was consistent with the optimized nitrogen treatment. Each community has an independent drip irrigation system, which can skilfully make fertilizer and irrigation separately. The drip irrigation belt is in the middle of each narrow row, with the heads 30 cm apart. An 18-litre container is installed behind the pressure regulator and controls the timing of each irrigation and fertilization by opening and closing the regulator port. Weeds are controlled by spraying pesticides and artificial weeding, and field diseases are controlled by spraying insecticides and fungicides. No obvious occurrence of weeds, pests and diseases occurred during the two-year experiment.

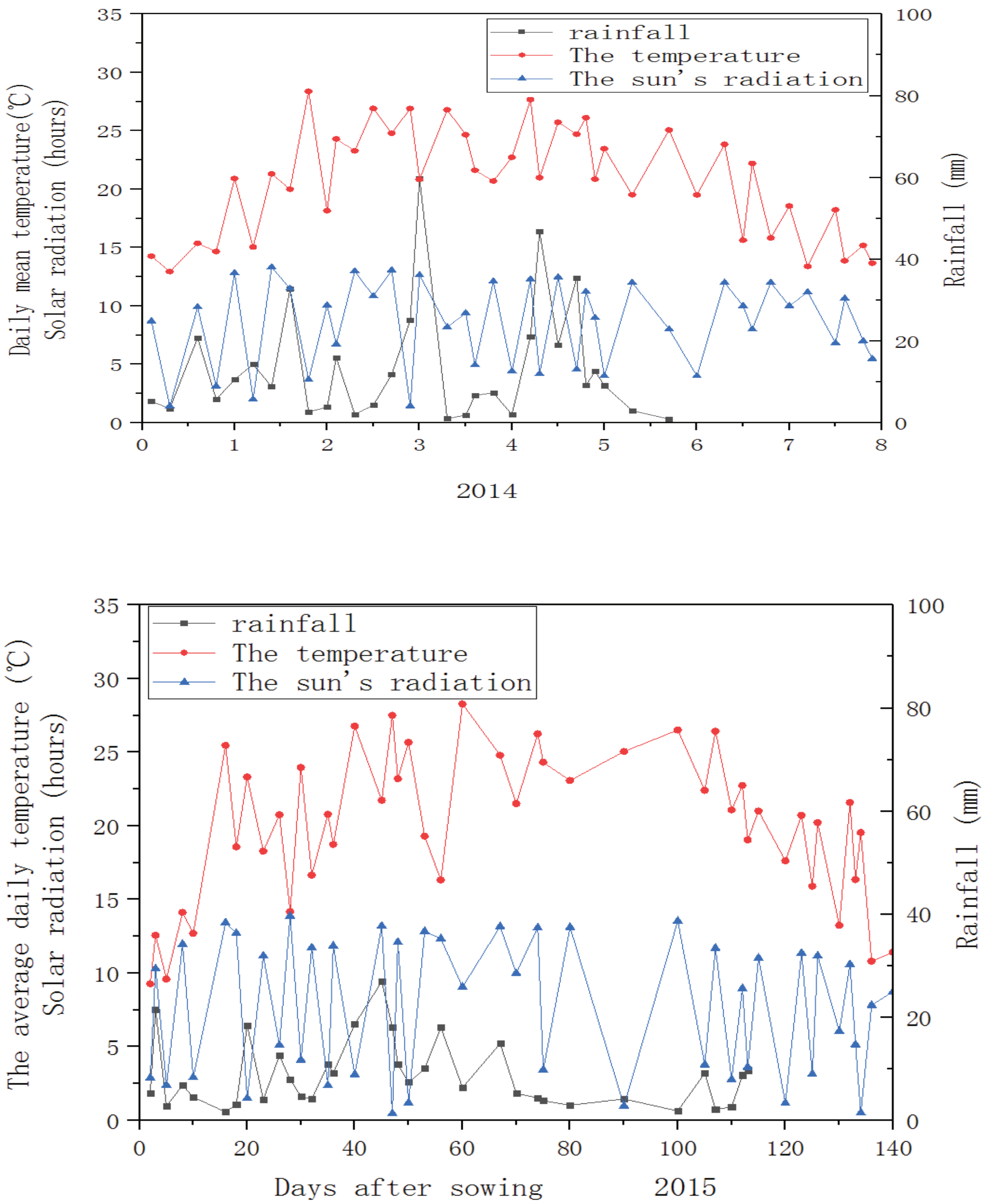

Fig. 1: Average daily temperature, solar radiation and rainfall during the 2014 and 2015 corn seasons.

Gas Collection Design

The CO_2 respiration rate and CH_4 emission flux of the ecosystem in vegetable field were collected by the static-dark box method, and the test device is shown in Fig. 2 (Zhang et al. 2017). The gas collecting box is composed of a base, an extension box and a top box. The base (length width height =50 cm 50 cm 10 cm) is made of stainless steel. The upper end (depth width = 3 cm 2 cm) is equipped with a sealing groove, which is sealed with water and liquid during sampling to prevent air leakage. There are 9 round holes with a diameter of 2cm on each side wall of the base to facilitate lateral migration of water, soil microorganisms and nutrients (Zhou et al. 2017). The top box and extension box are made of stainless steel. During sampling, the temperature inside the box shall be prevented from changing too fast, and the insulation material shall be covered externally. All boxes have the same volume (length width height = 50 cm 50 cm 50 cm), and extension boxes are added according to the growth height of plants. In order to fully mix the gas in the tank, two axial fans are arranged on the upper part of the top tank. Four samples were collected at each sampling point every 10min. The device used for soil respiration collection is a stainless-steel drum (20 cm in diameter and 25 cm in height), and a connected gas sample is installed in the middle of the top of the box (Sun et al. 2017).

In order to study the effects of mulching on the concentrations of CO_2 and CH_4 in soil at different depths, the concentration of CO_2 and CH_4 in upland was determined by diffusion chamber technique for nitrogen mulching and conventional treatment. The device consists of a collecting pipe (cylindrical PVC pipe, diameter 5cm, volume 1000 cm^3), rubber plug and a guiding pipe (polyethylene plastic pipe, inner diameter 1mm). During the leisure period, the diffusion tubes were buried in the soil layer of 10, 20 and 30 cm respectively, and the gas was extracted from the gas diffusion tubes at various depths successively with a 60 mL syringe. After sampling, the three-way valve was closed. The measurement frequency is once a week.

RESULTS ANALYSIS

Effects of Drip Irrigation under Film on Maize yield Difference were Analysed

The results showed that the average spring corn yield of farmers in northeast China under the traditional planting mode was 6.2 Mg/ha, with a variation range of 2.9 to 12.6 Mg/ha. The average yield of spring maize under percolation was 10.8 Mg/ha, with range of 3.0 to 15.8 Mg/ha. Compared with the traditional planting mode, the yield of farmers using drip irrigation increased by 74.2%.

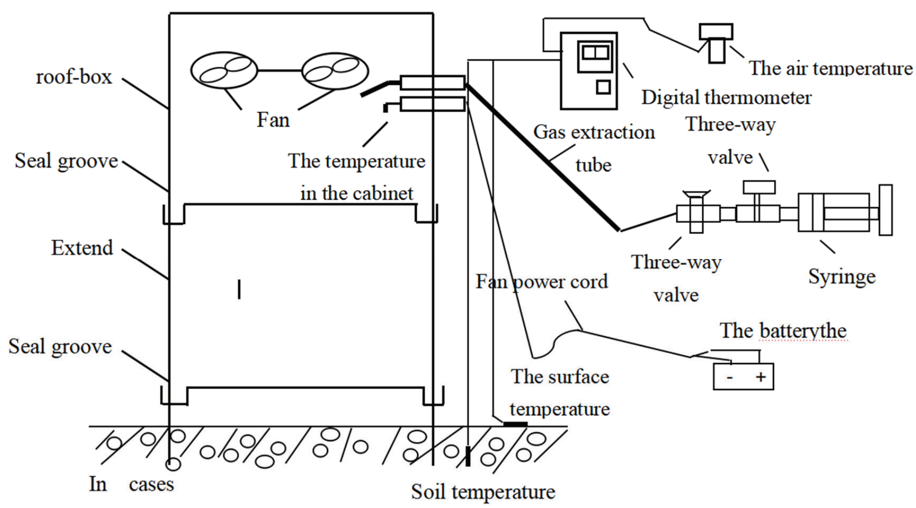

Fig. 2: Schematic diagram of greenhouse gas sampling process.

However, the average nitrogen application rate under drip irrigation was 335 Mg/ha, compared with the 184 kg/ha under conventional drip irrigation. The yield of drip irrigation maize under film was further analysed. The yield of drip irrigation maize under film was mainly distributed between 9-10 mg/ha with a distribution ratio of 48%, followed by 10-11 mg/ha with a distribution ratio of 19% and 8-9 mg/ha with a distribution ratio of 16%. Other intervals are less distributed. The main factors causing the current low yield of drip irrigation under film are as follows:

1. Nitrogen fertilizer management: The results showed the average nitrogen application amount of farmers under drip irrigation was 335 kg/ha and the amount of fertilizer application varied greatly among farmers, ranging from 206 kgN/ha to 570 kgN/ha, with 94% of farmers' nitrogen application amount exceeding 250 kg/ha. Further analysis showed that the nitrogen application amount was mainly distributed between 300- 400 kgN/ha, with a distribution ratio of 80%. In addition, 51% of the farmers applied basic nitrogen fertilizer once before sowing, and only 36% applied it. The farmers applied fertilizer twice, applying base fertilizer before sowing and top-dressing fertilizer at jointing stage.
2. Planting density: The results showed that under drip irrigation, the average planting density of farmers was 64,500 plants/ha and the range was 48,000 to 82,500 plants/ha. 97% of the farmers planted less than 75,000 plants per hectare. The maximum planting density was 60,000 plants/ha, with a distribution ratio of 29%.
3. Irrigation times: Under drip irrigation, the most frequent irrigation times were 3 times, with a distribution ratio of 33%. It was followed by two, with a distribution ratio of 23%. Again, 4 times, with distribution ratio of 20%. Other intervals are less distributed.

Analysis on optimal nitrogen management of drip irrigation maize under membrane

The application of nitrogen fertilizer significantly affected the grain yield, grain number per ear, 1000-grain weight and harvest index. Compared with no N treatment, N treatment increased yield by 19-48% and 80-145% respectively in 2014 and 2015, with significant difference. The yield difference was caused by the grain number per ear, 1000-grain weight and harvest index under nitrogen treatment were significantly higher than those without nitrogen treatment. The optimized yields in the two years were 13.0 and 14.6 Mg/ha, respectively, realizing 89% and 90% of the production potential of the year. Compared with 2014, the higher yield in 2015 was due to the higher accumulated temperature of the year. Analysis found that in 2015 > 10°C accumulated temperature is 30.16°C and 29.22°C is significantly higher than in 2014. Optimization of clever grain output by an average of 40%, two years ONR and 70% ONR treatment increased by 30% and 19% respectively. However, after optimization further increase in the amount of nitrogen fertilizer application rate showed no corresponding improvement in the clever grain output. At the same time, compared with the play washed processing, ONR processing Qiao grain yield significantly increased from 11.7 to 13.8 Mg/ha, with 2.1 Mg/ha increased yield, nitrogen fertilizer at the same time use to reduce the amount of 8 0kg/ha. In 2014 and 2015, to achieve maximum output the required minimum nitrogen respectively is 274 kg/ha and 272 kg/ha respectively. Optimal management of nitrogen fertilizer under submulch drip irrigation can greatly realize yield potential.

ANALYSIS OF GAS EMISSION

The change trend of mulching was consistent with that of conventional seasons, and the change trend of surface, underground 10, 20 and 30cm was similar. During the two-year planting period, the concentrations of 10 and 20 cm CH_4 on the surface and underground were relatively stable, and the concentration of CH_4 fluctuated between 1.5 and 3.0 ppm (1 ppm =10^{-6} V/V, the same below), while the concentration of 30 cm underground generally showed a trend of first rising and then falling, with the same rule in the second year. Single factor analysis of variance showed that the growing period of two years, under the effect of processing surface, underground 10, 20 and 30 cm CH_4 concentration difference significance ($P < 0.05$), the concentrations were 2.48, 2.31, 2.18, and 1.92 ppm; also under the normal processing surface, underground 10, 20 and 30 cm CH_4 concentration difference significance ($P < 0.05$), the concentrations were 2.48, 2.33, 2.20, and 1.97 ppm, therefore, CH_4 concentration decreased with soil depth deepening. For two years, cultivation of the soil CH_4 concentration matching t test, the effect of the soil CH_4 concentration decreases, but the effect of 10, 20, 30 cm underground CH_4 concentration difference was not significant. The effect of the underground CH_4 concentration effect is not obvious in the first year of planting period, coated surface, underground 10, 20 and 30 cm average CH_4 concentration were 2.34, 2.20, 2.06, and 1.80 ppm, conventional were 2.34, 2.18, 2.15 and 1.90 parts per million. In the second year, the average CH_4 concentrations of 10, 20 and 30 cm underground and surface were 2.59, 2.40, 2.28 and 2.03 ppm, respectively, while the conventional concentrations were 2.59, 2.47, 2.25 and 2.05 ppm, respectively. Paired t-test showed that in the first year, the concentration of 20 and 30 cm underground was significantly lower than that of conventional CH_4 ($P < 0.01$), while the concentration of 10cm underground had no significant effect. In the second year, the difference between different soil layers was not significant. CH_4 concentration decreases with the deepening of soil depth in two years. In the first and second years, the CH_4 concentration of 20 and 30 cm underground is significantly different from that of the surface ($P < 0.05$), while the CH_4 concentration of 10 cm is not significantly different from that of the surface ($P < 0.05$).The CH_4 concentration of 10 cm, 20 cm and 30 cm underground was significantly different from that on the surface ($P<0.05$). In the first year, the average annual concentration of 10, 20 and 30 cm CH_4 on the surface and underground was 2.24, 2.27, 2.21 and 2.06 ppm, respectively, while the conventional concentration was 2.24, 2.24, 2.24 and 2.19 ppm, respectively. In the second year, the average CH_4 concentration at the surface, 10, 20 and 30 cm underground was 2.52, 2.26, 2.11 and 1.84 ppm, respectively, while the conventional concentration was 2.52, 2.36, 2.09 and 1.98 ppm, respectively. Paired t test showed that the first year was significantly lower than the conventional 30 cm underground ($P < 0.05$), and the second year was not significantly different. In the first year, the annual average concentration of CH_4 on the surface and underground of 10, 20 and 30 cm was 2.41, 2.15, 1.95 and 1.61 ppm, respectively, while the conventional concentration was 2.41, 2.14, 2.08 and 1.68 ppm, respectively. In the second year, the annual mean concentration of CH_4 at 10, 20 and 30 cm underground was 2.66, 2.54, 2.43 and 2.18 ppm, respectively, while the conventional concentration was 2.66, 2.58, 2.40 and 2.10 ppm, respectively. Paired t test showed that the CH_4 concentration 20 cm underground in the first year was significantly lower than that in the conventional one ($P<0.05$), and the difference between the two was not significant in the second year.

CONCLUSION

Mulch drip irrigation can improve crop yield through rational fertilization, and it is found that the crop yield of one-time fertilization is higher than that of multiple fertilization, and effective nutrient management can improve yield potential. The CH_4 concentration in the sections treated with plastic-film mulching and conventional treatment decreased with the deepening of soil depth, but there was no significant difference in CH_4 concentration between the sections treated with plastic-film mulching and conventional treatment, that is, plastic-film mulching had no significant effect on the CH_4 concentration in the sections. The CH_4 concentration in the soil layer 10 and 20 cm underground is mainly affected by the surface CH_4 concentration. The CH_4 concentration in the soil layer 30 cm underground is not only affected by the surface CH_4 concentration, but also affected by the surface and underground temperature. In the future, it is necessary to improve the environmental effect evaluation of the integrated management system of drip irrigation under membrane and further integrate it with international work.

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