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Agronomic and Ecological Evaluation on Growing Water-Saving and Drought-Resistant Rice (*Oryza sativa* L.) Through Drip Irrigation

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Abstract

A field demonstration trial comparing the growth status, yield ability and water use efficiency of drought-tolerant rice (*Oryza sativa* L.) varieties and normal paddy rice variety under drip irrigation and paddy irrigation was carried out for two years in Shanghai, China. Under drip irrigation, both inbred and hybrid water-saving and drought resistant rice (WDR) varieties showed better yield capacity than paddy rice varieties tested. WDR varieties under drip irrigation attained more than 95% of the yield level that is achieved in paddy field, while the paddy varieties under the same drip condition reached only about 75%.The methane gas emission was obviously decreased under drip irrigation condition, while the emission of other greenhouse gas like nitrous oxide or carbon dioxide was not observed significant difference between drip and paddy irrigation. It could be concluded that it is practicable to grow water saving and drought resistant rice through drip irrigation. Drip irrigation maintained a competitive grain yield and water productivity, and greatly reduced pollution risk to the environment. Considering the conservative amount of fertilizer application, less than the amount of fertilization in normal paddy field, the yield potential of rice could be improved by increasing the amount of fertilizer as top application in drip irrigation system.

Keywords: drip irrigation, drought tolerance, gas emission, rice (*Oryza sativa* L.), soil drainage, water use efficiency

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important food crops in the world which is mainly grown in Eastern and Southern Asia. It is grown in a wide range of environments and productive in many situations where other crops would fail. Rice-growing environments are based on their hydrological characteristics which include irrigated, rain fed lowland, upland. Water - nature's gift to mankind is not unlimited and free forever. The amount of water present in the universe is only about 1520 million cubic kilometers, 97% is ocean and sea water, 2% is frozen arctic waters and only 1% is water in lakes, rivers and underground water, which is portable water for direct use to humans (Shaker, 2004). However rice farming consumes about 50% of water resources used in all economic activities (Fan et al., 1996; FAO, 2010; World Bank, 2010), which is taken as the largest consumer of water resources.

There are warnings that food production is likely to be seriously constrained by freshwater shortages in the near future. It has been observed that the need for irrigation water is likely to be greater than currently anticipated, and the available supply of it less than anticipated (Smith & Gross, 1999). The available amount of water for irrigation, however, is becoming increasingly scarce due to decreasing resources, declining water quality and increasing competition among multiple water users and environmental factors in many countries of the world. The pressure to reduce water use in irrigated agriculture is mounting, especially in Asia, where it accounts for 90% of total diverted fresh water. Rice is an obvious target for water conservation: it is grown on more than 30% of irrigated land and accounts for 50% of irrigation water. Worldwide, about 80 million ha of irrigated lowland rice provide 75% of the world's rice production. These systems remain the most important rice production systems for food security, particularly in Asian countries. Reducing water input in rice production can have a high societal and environmental impact if the water saved can be diverted to areas where competition is high. A reduction of 10% in water used in irrigated rice would free 150,000 million m^3, corresponding to about 25% of the total fresh water used globally for non-agricultural purposes (Klemm, 1999).

The yield ability of rice depends not only on the varieties but also the availability of irrigation water and soil fertility or fertilizer application. In most parts of the rice growing regions, rice growth encounters the abiotic stress of either flood or water deficiency to the opposite, especially during the period of seasonal water shortage which is becoming a limiting factor to yield improvement in many South-Eastern Asian regions. Meanwhile, for most varieties of rice, nitrogen fertilization during the tillering stage contributes to increase in yield. Rice plants in the paddy field mostly use the water in the upper layer of soil, and hardly ever take water and nutrients from deeper soil level, thus resulting in run-off of some nutrients from fertilizer application to the surrounding water system or to underground water through soil leaching, causing nutrient pollution to the surrounding water resources. While saving water is undoubtedly a main concern, protecting the quality of our water may be even more important. Every day, China's increasing urban centers and expanding industrial uses put more and more pressure on the quality of our water resources.

Furthermore, unavailability of irrigation is a major cause of yield reduction and even cause complete yield loss in rice production especially for the late cropping season from July to October in Southern, Central and Western China. Therefore, efficient irrigation system is necessary for bumper harvest of rice. Traditionally, irrigation systems need construction of huge reservoirs or dams with long and very complex irrigation channels which are often costly and labor intensive to construct and maintain well. In some parts of the world, sprinkler irrigation facilities are in use but this also amounts to water wastage. Drip irrigation is a more convenient choice of irrigation system as it could supply rice growth with water and the nutrients dissolved in the water in a relatively flexible way. It is possible to establish drip irrigation in situ as long as there is water source from a well dug out from underground or from a river nearby. Drip irrigation is considered as an alternative irrigation approach for better water and fertilizer usage efficiency (Assouline, 2002; Hanson & May, 2003; Eid et al., 2013). Drip irrigation (trickle or micro irrigation) is a promising system for economizing on the available irrigation water. It is also necessary to manage the available water efficiently for maximum crop production. Drip irrigation can supply water both precisely and uniformly at a high irrigation frequency compared to furrow and sprinkler irrigation, thus potentially increasing yield, reducing subsurface drainage, providing better salinity control and better disease management since only the soil is wetted whereas the leaf surface stays dry (Hanson & May, 2007). However, there are still many things unclear about the practicability of this irrigation system as to the water use efficiency on rice plant, the yield ability, impact to environment and the production cost.

Thus, this project carried out in the suburb of Shanghai aimed at exploring the possibility of growing more and environment-friendly rice with less water through joint application of water-saving and drought-resistant rice (abbreviated as WDR, Luo, 2010) and drip irrigation system. The growth status, yield ability and water use efficiency, the amount of soil drainage and emission of greenhouse gases of drought-tolerant rice varieties and normal paddy rice varieties under both drip irrigation and traditional paddy field were investigated. From the comparison, the practicability of drip irrigation in rice production in Shanghai will be revealed.

2. Materials and Method

2.1 Experimental Design

A pair of comparative field demonstration experiments was designed and carried out in the experimental station of Shanghai Academy of Agricultural Sciences at Zhuang Hang Town, Feng Xian District of Shanghai City from 2010 to 2012. The first year was set for pre-trial. Of two treatments, one was carried out with drip irrigation in a field, and the other was paddy field maintaining a shallow layer of water for all the growth stage in a neighboring field. The amount of irrigation for both fields was recorded by water meters. The drip facility was from Netafim Israel and Tianye Group of China. Drip pipes (lateral pipes) were laid on the soil surface. Lateral pipe interval was 50 cm and the spacing of drippers was 30 cm. The varieties of rice used were two *O. sativa* japonica subspecies (inbred cultivars), namely Huhan 3 and Jinfeng and two *O. sativa* indica subspecies (hybrid combinations), namely Hanyou 73 and Xieyou 702. Varieties of Huhan 3 and Hanyou 73 were WDR, while Jinfeng and Xieyou 702 were paddy rice. The two trial fields were adjacent with the same acreage of 6.5 mu (666.67 square meters per mu, i.e.

1/15 hectare). Random plot design was applied. And each field was divided into 4 plots for the four varieties respectively and varieties were randomly arranged into these plots.

Based on the natural precipitation during the field trial (according to the meteorological station rain gauge records in the experimental station), additional irrigation was supplied by drip irrigation facilities. According to preliminary results in previous years, the amount of irrigation by drip was set to 200 cubic meters per mu (3000 $m^3 \cdot ha^{-1}$). When the soil is dry, drip irrigation was given till the soil around the plant became moist.

2.2 Sowing Rice Seed

For the field trial, rice seeds were directly sown in late May in both 2011 and 2012. The planting interval was 30 cm between and 20 cm within rows. Two to three seeds were sown per hole. After the seedling establishment, paddy field was watered to maintain a thin layer of water, while drip field was maintained from dryness with drip irrigation. All the rice varieties were harvested in the late October.

2.3 Fertilization and Other Field Management Practices

The fertilization application was 25 kg per mu of bulk blending fertilizer (N : P : K = 24 : 8 : 10) as base application. Additional 22.5 kg per mu of urea was applied in two splits through drip irrigation or by broadcasting in the paddy field during early tillering and tillering stage. No other fertilizers were applied during the whole growth stage.

2.4 Measurement of Drainage in the Soil Layer

Soil drainage at the soil depth of 30 cm was collected and measured by a soil solution sampling device, a vacuum tube with ceramic head (31 mm in diameter and 80 cm in length). The air inside the tube, which is buried in the soil to the depth of measurement, is taken out until a vacuum condition is formed in side thus allowing the drainage to penetrate into the tube through the ceramic head. After 5 - 6 days, a sampling bottle connected to a manual pump is used to suck/syphon the drainage collected inside the tube and drainage was measured.

2.5 Measurement of Greenhouse Gas Emission: CH_4, N_2O, CO_2

Greenhouse gas sample such as CH_4, N_2O, and CO_2 was collected and measured on August 3, 10, 17, and 24. Gas was collected by the method of close chamber at 5, 10, 15, 20 min after closing chamber on the soil with the rice plants growing inside it. GC-MS was used to measure the concentration of these gases.

3. Results

3.1 The Growth Status at Different Stages

During the growth season, the average total rainfall received was 510 mm (7650 $m^3 \cdot ha^{-1}$). The growth status of rice in the field trial was recorded as in the photo panels of Figure 1. The establishment of seedlings was nice and under the open conditions, normal growth was observed due to the water supply and drip irrigation, although, in the drip field, the maturity was 2 to 3 days late. This might be due to decrease in chlorophyll content in the plant as increase in chlorophyllase activity limits chlorophyll synthesis under water limited environment, especially in the late stage. Lafitte and Courtois (2002) reported decline in chlorophyll content under drip irrigation than conventional method. Subsurface drip system improved the uptake of essential nutrients (Vanitha, 2012).

More interestingly, drip irrigation grown drought-saving rice maintained green leaf sheath of the base leaves (Figure 1. G). According to field investigation result, the infection rate of sheath blight was 25% in the paddy field grown rice while in the drip grown field, the infection rate of sheath blight was less than 2%. The number of pests such as rice plant hoppers (such as *Nilaparvata lugens* and *Laodelphax striatellus*) in the drip irrigation field was also significantly lower than that in the paddy field with flooded irrigation (Figure 1. C).

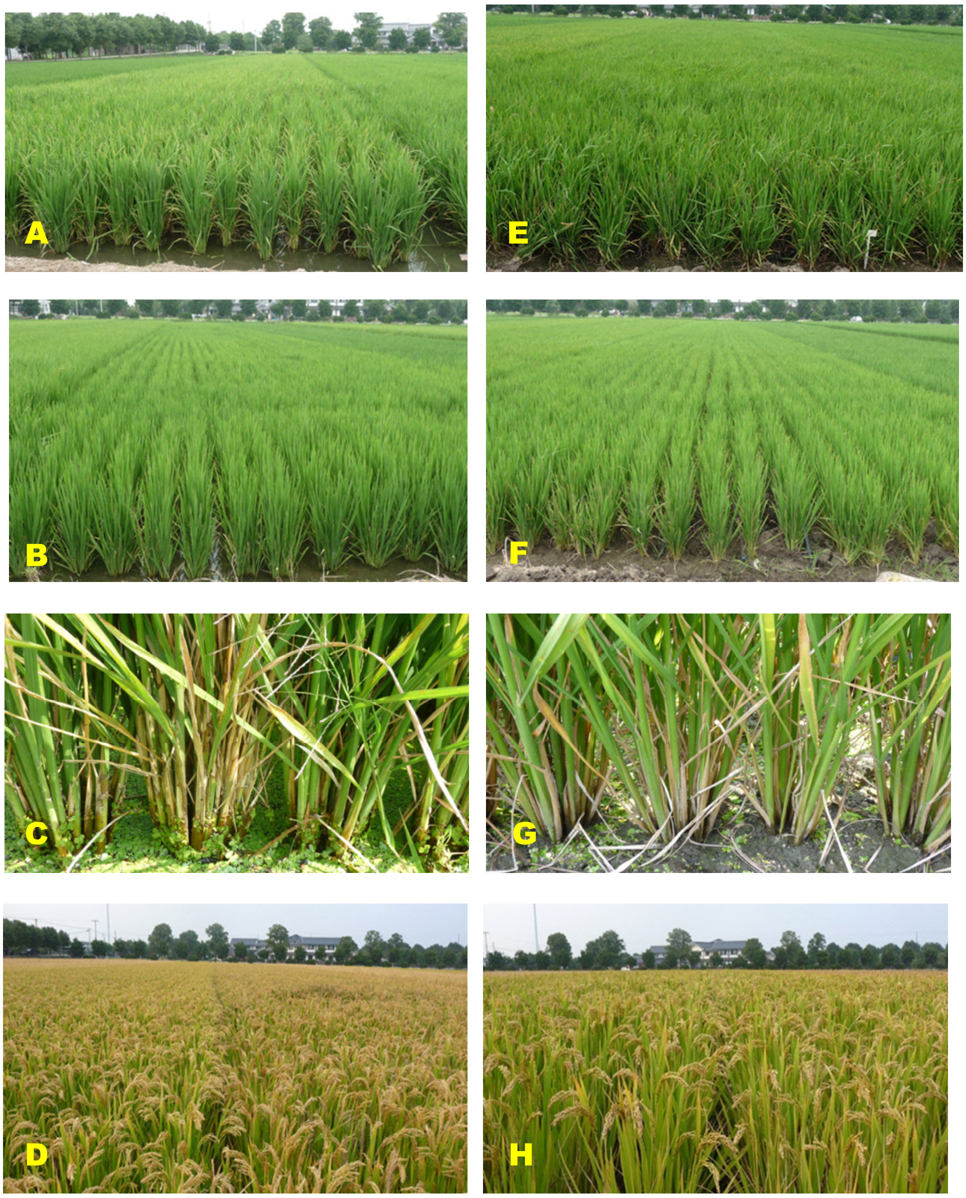

Figure 1. Growth status of rice plants (cv. Huhan3) at tillering, booting and maturity stages in the paddy field (A, B, C and D) and drip irrigation field (E, F, G and H) in the year of 2012

3.2 Grain Yield

According to the plot harvest, rice grain was sun dried to about 14% moisture content, and the average yield result for the two years field trial is showed in Figure 2 and Table 1. Under the paddy field irrigation condition, grain yield per unit area for the water-saving and drought resistant rice (WDR) Hanyou 73 (hybrid *indica* rice) did not attain the yield level of the control variety Xieyou 702 (hybrid *indica* rice), as showed in the two open bars to the left side of Figure 2. For the inbred *Japonica* variety, water-saving rice variety Huhan 3 harvested a significantly higher yield than paddy rice variety Jinfeng (inbred *Japonica*), showed in the two open bars to the right side of Figure 2, reflecting the variety characters.

Under drip irrigation, water-saving and drought resistant rice of both Hanyou 73 (hybrid *indica* rice) and the inbred *Japonica* variety Huhan 3, achieved a significantly higher grain yield than the control paddy varieties Xieyou 702 (hybrid *indica* rice) and Jinfeng (inbred *Japonica*), shown in the light gray bars (Figure 2). It is interesting to notice that the grain yield of both WDR varieties Hanyou 73 and Huhan 3 under drip irrigation reached more than 95% of the yield level that achieved under paddy field, while the yield of paddy varieties Xieyou 702 and Jinfeng under drip irrigation reached only about 75% of the yield level that was achieved under paddy field (Table 1).

Water use efficiency (WUE) is a quantitative measurement of how much biomass or yield is produced over a growing season, normalized with the amount of water used up in the process. Besides absolute yield, WUE is an important agronomic factor, especially in agricultural irrigation systems. In this study, regardless of the difference in varieties, such as WDR varieties and normal paddy rice varieties, great difference in water use efficiency was observed between drip irrigation and paddy irrigation (Table 1). For WDR varieties, the water use efficiency of both Hanyou 73 and Huhan 3 under drip irrigation was over 70% higher than the paddy irrigation, while for paddy rice varieties of Xieyou 702 and Jinfeng, the WUE under drip irrigation was around 35% higher than the paddy irrigation.

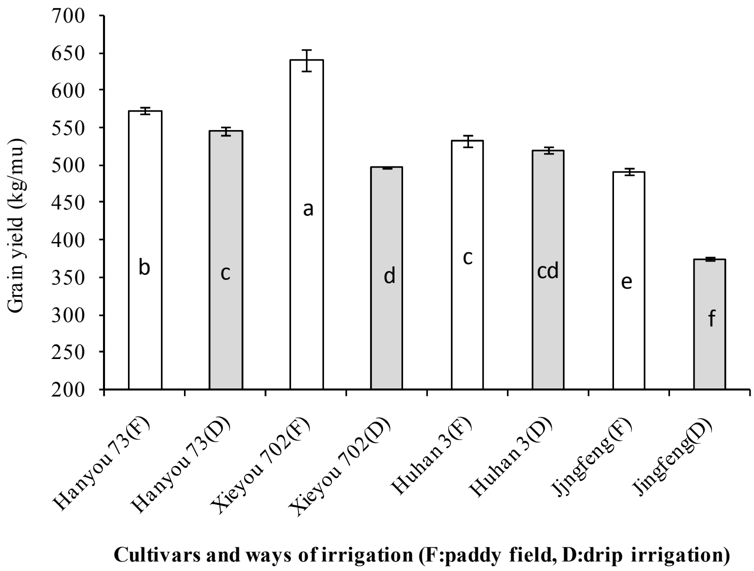

Figure 2. Comparison of grain yield among different cultivars and irrigation methods

3.3 Greenhouse Gas Emission Analysis

After rice growth entered into active tillering stage, the greenhouse gas emission was measured from the drip irrigation and paddy field (Hanyou 73 and Xieyou 702 plots to be precise). The methane gas emission from the drip irrigation field basically maintained a lower level, equivalent to that of the open air, less than 5 ppm, while the paddy field produced significantly higher methane gas emission, higher than 20 ppm (Figure 3). Methane gas emission showed the same trend as in the year 2010, 2011 field trials. The result coincided with other related studies on different cropping system of rice. Drip irrigation could be a good choice as an alternative rice cropping system since it reduced greenhouse gas emission greatly and with comparable yield as in paddy field condition. One of the factors resulting in methane gas emission from rice fields is the standing water and the anaerobic decomposition of organic matter. In this experiment, the result showed that drip irrigation could effectively prevent or greatly reduce this gas emission from rice fields.

Table 1. Comparison of grain yield and water use efficiency between drip grown and paddy grown rice

Varieties	Drip irrigation (Drip 3000 + rain fall 7650 m^3 ha^{-1})			Paddy field (Irrigation 11250 + rain fall 7650 m^3 ha^{-1})			Water saving of drip irrigation compared with paddy based on WUE (%)	Yield ratio of drip irrigation to paddy
	Yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})	Variety comparison	Yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})	Variety comparison		
Hanyou 73	8187.0	7.69	110.02	8584.5	4.54	89.35	40.91	0.95
Xieyou 702	7441.5	6.99	100.00	9607.5	5.08	100.00	27.25	0.77
Huhan 3	7798.5	7.32	138.90	7980.0	4.22	108.24	42.34	0.98
Jingfeng	5614.5	5.27	100.00	7372.5	3.90	100.00	26.01	0.76

The data was the average of the two year field trials.

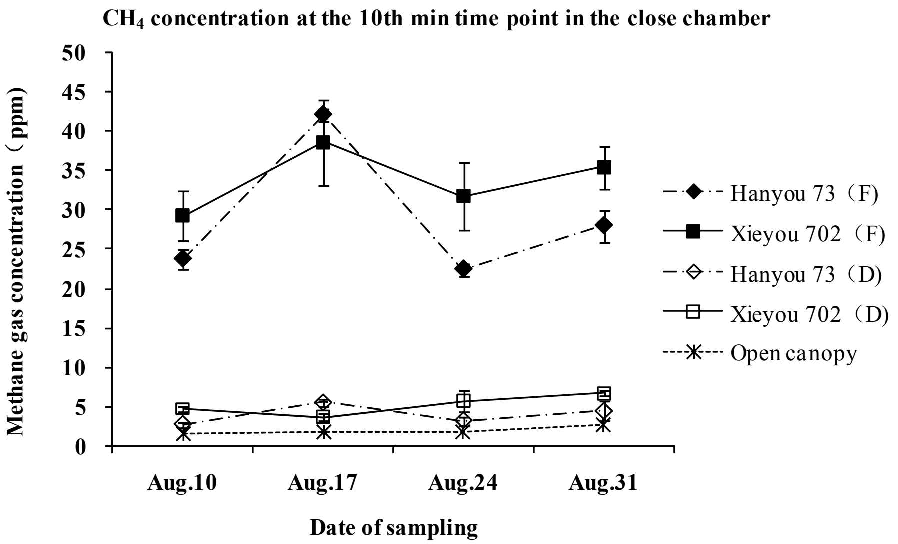

Figure 3. CH_4 emission at the 10th minute time point in the close chamber in 2012 field trial

The other two greenhouse gases measured, namely CO_2 and N_2O, had no significant difference in the measurements from the two different irrigation systems, which was in the same trend as in 2010 and 2011 year trials, although the exact concentration of CO_2 and N_2O was not the same. In the drip irrigation rice field, the CO_2 concentration was obviously lower than that of the open air (Figure 4). It is reasonable to explain the result since photosynthesis in the rice plant canopy consumed carbon dioxide causing a reduction of its concentration in the close chamber. But the concentration of N_2O was not significantly different among the different irrigation systems and open air (Figure 5).

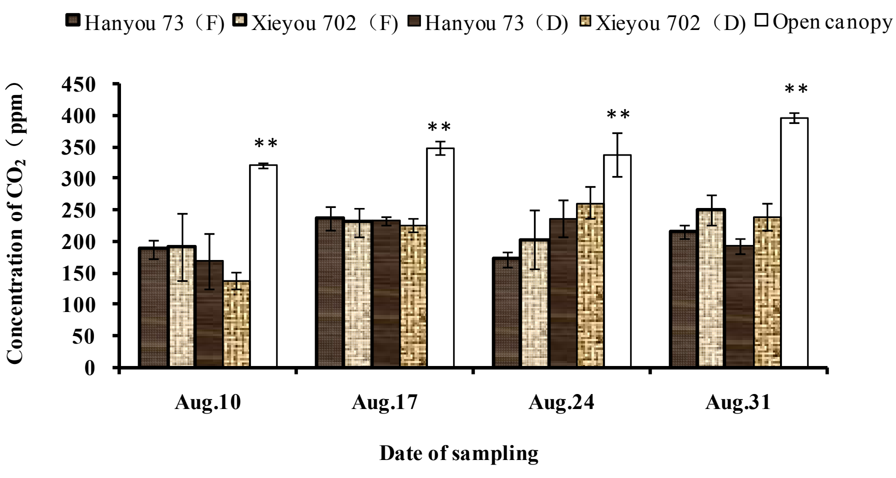

Figure 4. CO_2 concentration at the 10th minute time point in the close chamber in 2012 field trial

** indicates significant difference at $P<0.01$.

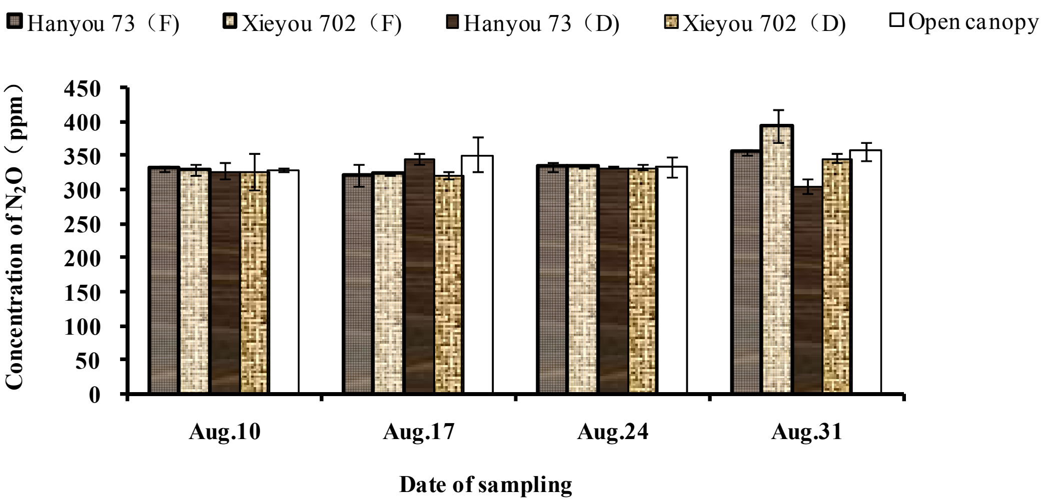

Figure 5. N_2O emission at the 10th minute time point in the close chamber in 2012 field trial

3.4 Effect of Drip Irrigation on Soil Drainage Solution

The amount of soil drainage at the depth of 30 cm soil layer was monitored from the paddy field and drip irrigation for 4 weeks from August to September. There was always a shallow water layer in paddy field during the growth stage. For all the four periods of investigation, paddy field growing both varieties Hanyou 73 (F) and Xieyou 702 (F) released higher amount of soil drainage solution, which was around 30 ml per day regardless of varieties, while the drip irrigation plots for growing Hanyou 73 (D) and Xieyou 702 (D) caused a much less amount of soil drainage, less than 10 ml per day (Figure 6). The volume of drainage between drip and paddy irrigation was significantly different. The result depicts that drip irrigation would cause the least potential risk of polluting the underground water system through excessive soluble nutrients in the drainage.

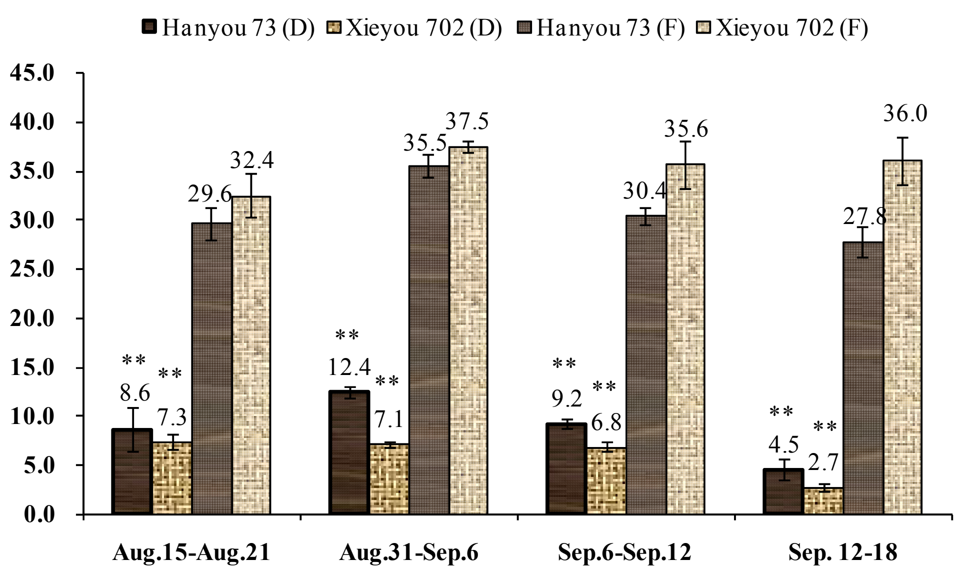

Figure 6. Comparison of soil drainage in the 30 cm depth of soil layer in 2012 field trial

** indicates significant difference at $P<0.01$.

4. Discussion

Water saving and drought resistant rice (WDR) is defined as a new type of rice variety which has both the high yield potential and good quality of the current paddy rice, and as well as the capacity of water saving and drought resistance of upland rice (Luo, 2010). From the results of the field trials, difference in grain yield was observed from the different varieties and the different irrigation methods. At first under paddy irrigation condition, for the *indica* hybrid rice combination, Hanyou 73, a WDR hybrid did not perform better than the paddy variety Xieyou 702, but the inbred *japonica* variety, Huhan 3, a WDR variety showed significantly higher yield capacity than the paddy variety Jinfeng. Under drip irrigation however, a kind of soil condition similar to upland, both inbred and hybrid WDR varieties showed better yield capacity than paddy rice varieties tested. So, the WDR could also be described as a kind of intermediate of paddy rice and upland rice.

Water use efficiency (WUE) is an accurate indicator of agricultural productivity in relationship to crop's consumptive use of water. In these field trials, WUE results reflected exactly the same trend as grain yield. WUE of rice in this experiment under paddy irrigation was between 3.9 to 5 kg ha^{-1} mm^{-1}, similar or a bit higher than that achieved in the other part of the world (Abdul-Ganiyu et al., 2012). However, under drip irrigation, the WUE was increased by 35 to 70% depending on different varieties, especially for the WDR variety, WUE was increased by more than 70%, which is consistent with other studies showing improved water productivity of aerobic rice compared to flooded rice (Grassi et al., 2009). This is due to the amount of water supplied with drip irrigation which is sufficient to saturate the soil during reproductive stage resulting in better spikelet fertility and finally the yield. Westcott and Vines (1986) had reported that florets per panicle and specific grain weight are the best predictors of yield. Similar trend was observed by Sritharan et al. (2010), Soman (2012), and Vanitha (2012) on rice in India and Ahmed et al. (2010) on banana in Sudan. The authors recorded considerable increase in yield under drip irrigation as compared to flooded field or sprinkler irrigation. Sritharan et al. (2010) reported that water productivity increased significantly as compared to flooded irrigation while investigating the effect of micro-irrigation technique in aerobic rice. The result in this study supported the use of drip irrigation in improving crop's water use efficiency.

Usually, methane gas emission increases in the paddy flooded rice field, while in the upland nitrous oxide (N_2O) release from the soil rises (Neue & Sass, 1994; Xing et al., 2009). However, in this study, drip irrigation kept the field in the condition similar to upland throughout the growing season, resulting in no significant increase in N_2O from the soil. Application of fertilizers through drip irrigation system (fertigation) can reduce fertilizer usage, minimize leaching by rain and excessive irrigation, maximize the fertilizer use efficiency, allows flexibility in timing of fertilizer application, and reduces the labour required for applying fertilizer (Ahmed et al., 2010). Pressurized irrigation systems (sprinkler, surface and subsurface drip) has been reported to have the potential to increase irrigation water use efficiency by providing water to match crop requirements, reducing runoff and deep drainage losses, and generally keeping soil drier reducing soil evaporation and increasing the capacity to capture rainfall (Camp, 1998). This may explain the effect on water saving of low rated, low flow drip irrigation in this experiment.

There are numerous reports of large irrigation water savings when changing from continuously flooded rice to saturated soil culture or alternate wetting and drying, but yields decrease as soil water content declines below saturation (Bouman et al., 2002). Owing to this and growing water shortage in the dry season, utilization of water-saving and drought-resistant varieties is another important choice for growing rice in the area with limited water supply. Even in regions with bumper water resource from rainfall for irrigation, cultivation of drought-resistant rice varieties could contribute to saving cost on irrigation facilities and reduction in underground water pollution due to nutrient leaching from soil or run-off of soil surface water. The environmental effect of planting rice in flooded field goes beyond underground water pollution but also the emission of greenhouse gases which could cause the depletion of the ozone layer. Many literatures have recorded the emission of methane, nitrous oxide and carbon dioxide gases in rice anaerobic fields. The planting of drought-resistant rice varieties is also useful in decreasing greenhouse gas emission from the paddy soil as it needs no flooding layer of water in the field.

The merit of environmental friendliness of drip irrigation was achieved from this experiment, especially with the methane gas emission which was obviously decreased in the drip irrigation system. As it is clear that the green house effect of methane gas was more than 20 times greater than carbon dioxide (EPA, 2010), it is significant that drip irrigation system maintains comparable grain yield with paddy irrigation but decreases greenhouse gas emission. It could be concluded that it is practicable to grow water saving and drought resistant rice through drip irrigation. Drip irrigation maintained a competitive grain yield and greatly reduced pollution risk to environment. Considering the conservative amount of fertilizer application, less than the normal amount of fertilization, the yield potential of rice could get to a higher level if the amount of fertilizer as top application in drip irrigation system is increased.

Challenges encountered in the experiments in the last three years included the effective sowing methods and weed control. Direct sowing is the ideal way of sowing but often faced poor establishment of seedlings because of the bad soil structure caused by strong rainfall during the sowing season in Shanghai or some other parts of the rice growing region in Southeastern China. These two problems need to be solved in the near future.

Acknowledgements

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