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THE EFFECTS OF DIFFERENT WATER REGIMES ON GROWTH AND WATER USE EFFICIENCY IN SEEDLING STAGE OF SOME RICE VARIETIES (*Oryza sativa* L.)

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ABSTRACT

Six rice (*Oryza sativar* L.) varieties (Beodien, KD18, Koshihikari, Sensho, Rayada) were used to evaluate genotypic variation in growth and water use efficiency in the response to different water regimes at seedling stage. Five days after sowing, seedlings were thinned to one plant per pot and water treatments; flooding as a control, well-irrigated (24% Soil moisture content (SMC) (w/w)) and drought (12% SMC) were applied. The results of this experiment indicated that shoot dry weight (SDW), root dry weight (RDW), total dry weight (TDW), leaf area (LA), water use (WU) and water use efficiency (WUE) of Rayada, Sensho, KD18 and IR24 were not significantly different between control and well-irrigated conditions. Those of Koshihikari and Beodien in well-irrigated were lower than those in control. In the aerobic conditions (24% and 12% SMC conditions), total root length (RL), root surface area (RSA) tended to increase in almost varieties except Koshihikari. RL, RSA and root volume (RV) of Koshihikari in the aerobic conditions were lower than those in control. Among varieties used, Rayada had the highest value in RL, RSA, RV, SDW, TDW, LA and WU, followed by Sensho. Moreover, Rayada had also the highest value in WUE in drought conditions, followed by Sensho. Although KD18 and IR24 had lower values in LA, SDW, RDW, TDW, and WU at all treatments, these characters were not severely affected by drought compared with other varieties. The results suggested that Rayada and Sensho are suitable with aerobic rice system and Koshihikari is not adaptable. *Indica* lowland rice varieties, KD18 and IR24 may be desirable drought tolerant varieties compared with *japonica* lowland rice variety, Koshihikari.

Keywords: Drought, rice seedlings, soil moisture content.

Ảnh hưởng của các độ ẩm đất khác nhau đến sinh trưởng và hiệu quả sử dụng nước của một số giống lúa (*Oryza sativa* L.) ở giai đoạn cây con

TÓM TẮT

Thí nghiệm nghiên cứu ảnh hưởng của độ ẩm đất đến các đặc điểm sinh trưởng và hiệu quả sử dụng nước ở giai đoạn cây con của 6 giống lúa (*Oryza sativar* L.) (Beodien, KD18, Koshihikari, Sensho, Rayada). 5 ngày sau gieo hạt, tỉa để lại 1 cây ở mỗi chậu và bắt đầu xử lý độ ẩm đất với 3 mức: đối chứng là cho ngập nước; duy trì độ ẩm đất 24% (24%SMC)-độ ẩm tối ưu; độ ẩm đất 12% (12% SMC)-hạn. Kết quả của thí nghiệm chỉ ra rằng, khối lượng chất khô của thân lá (SDW), khối lượng chất khô của rễ (RDW), tổng khối lượng chất khô của toàn cây (TDW), diện tích lá (LA), lượng nước sử dụng (WU) và hiệu quả sử dụng nước (WUE) của 4 giống Rayada, Sensho, KD18, IR24 không có sự sai khác có ý nghĩa 95% giữa công thức đối chứng và công thức độ ẩm đất 24%. Hai giống Koshihikari và Beodien ở công thức độ ẩm đất 24% cho giá trị thấp hơn so với công thức đối chứng đối với các chỉ tiêu trên. Ở công thức độ ẩm đất 24% và 12%, tổng chiều dài rễ (RL), diện tích bề mặt rễ (RSA) có khuynh hướng tăng ở hầu hết các giống trừ giống Koshihikari. RL, RSA, thể tích rễ (RV) của giống Koshihikari trong điều kiện hảo khí thấp hơn công thức đối chứng. Giống Rayada đạt giá trị về RL, RSA, RV, SDW, TDW, LA và WU cao nhất so với các giống còn lại, kế đến là giống Sensho. Ngoài ra, giống Rayada còn đạt giá trị cao nhất về hiệu quả sử dụng nước (WUE) trong điều kiện hạn, kế đến là giống Sensho. Hai giống KD18, IR24 có giá trị về LA, SDW, RDW, TDW và WU thấp hơn so với các giống còn lại ở tất cả các công thức. Tuy nhiên, trong điều kiện hạn thì hai giống này không bị ảnh hưởng nhiều như các giống còn lại. Từ kết quả thí nghiệm cho thấy rằng hai giống Rayada, Sensho phù hợp với hệ thống canh tác hảo khí, giống Koshihikari không phù hợp. Giống lúa nước *indica* KD18 và IR24 thích hợp với điều kiện hạn hơn giống lúa nước *japonica* Koshihikari.

Từ khóa: Độ ẩm đất, hạn, lúa ở giai đoạn cây con.

1. INTRODUCTION

Drought is one of the critical problems for agriculture caused by global climatic change. Drought has been affecting 20% of the total rice-growing area in Asia (Pandey and Bhandari, 2008). Rice production consumes about 30% of all freshwater used worldwide. In Asia, more than 150 million hectares are irrigated and cultivated area, meanwhile 40-46% of rice crop is involved. At the field level, rice receives more 2-3 times of water than other crops (Pandey et al., 2007). However, scarcity of freshwater has threatened the production of the flood-irrigated rice crop (IWMI, 2000). Drought-prone area was estimated at least 20 percent total rice area in Asia, this number was also indicated 10 percent in Vietnam (Pandey et al., 2007). Thus, recently, the rice production of Vietnam has been seriously affected by drought.

Rice (*Oryza sativa* L.) is a sensitive crop to water stress. Approximately 50% of the rice production of the world is affected by drought (Bouman et al., 2005). Advanced technologies development will maintain or increase rice production in the face of declining water resources. Recently, several methods have been found by agricultural scientists to reduce water loss and increase the water productivity of the rice plant such as alternate wetting and drying (AWD) (Tabbal et al., 2002), ground cover systems (Lin et al., 2002), system of rice intensification (Stoop et al., 2002) and a new water-saving technologies “aerobic rice systems” (Bouman et al., 2005). Aerobic rice systems keep fields remaining unsaturated throughout the season. George et al. (2002) showed that the aerobic conditions are known as a free draining, non-flooded, and non-puddled soil with soil moisture content at below saturation. This method promises substantial water saving by minimizing seepage, percolation and greatly reducing evaporation (Bouman et al., 2002). Matsuo and Mochizuki (2009) proved that aerobic rice systems could save more than 47% of irrigation water in comparison with AWD. So, aerobic rice system is one of promising advanced technologies to reduce water loss and to increase the water productivity of rice plant. The present experiment is conducted by application this method with some modifications.

Besides new technologies, drought resistant cultivars should be considered to be those that possess drought resistant traits and produce higher yield than others under drought conditions. In Asia, upland rice is already grown aerobically with minimal inputs in the upland environment, but almost as a low-yielding subsistence crop to give stable yield (Lafitte et al., 2002). Upland rice varieties are drought tolerant, but have a low yield potential. Besides, high-yielding lowland rice varieties grown under aerobic soil conditions, severely decreased yield. Bouman (2005) supposed that aerobic rice genotypes are new classes of upland adapted genotypes with improving lodging resistance, harvest index, input responsiveness and tolerance to occasional flooding. These varieties can combine the drought-resistant characteristics of upland varieties with the high-yielding characteristics of lowland varieties (Lafitte et al., 2002).

Previous studies of aerobic rice systems have focused on comparing morphological and physiological traits such as root parameters, shoot dry weight, root dry weight, stomatal conductance, yield and yield components of aerobic rice with those observed under flooded paddy conditions (Bouman et al, 2005; Matsuo and Mochizuki, 2009; Matsuo et al., 2009). This information is necessary for the selection and breeding of high-yielding aerobic rice cultivars in the future. However, there has been only limited information in crop performance between aerobic and flooded conditions.

The objectives of this study were to analyze genotypic variation in Growth and WUE in the response to different water regimes.

2. MATERIALS AND METHODS

2.1. Plant materials

Six rice varieties were used: two Vietnamese *indica* rice varieties, Beodien (upland) and KD18 (paddy); two *japonica* rice varieties, Koshihikari (paddy) and Sensho (upland); and two *indica* paddy rice varieties, IR24 and Rayada.

2.2. Growth conditions

The experiment was conducted in Biotron of Faculty of Agriculture, Kyushu University with constant temperature at 25^{0}C, 70% of humidity, 12h photoperiods and 250µM m^{-2}s^{-1} of light intensity at day time. Three pre-germinated seeds were sown in a1/10000a plastic pot contained sandy clay loam soil (20.7% clay, 23.2% silt, and 56.1% sand) with 12% of soil moisture content (SMC). We used a1/10000a Wagner pot with a diameter of 127mm and a height of 198mm (ICM, Tsukuba) contained with 1,0kg dried sandy clay loam soil with 2g chemical fertilizers (16%N : 16%P_2O_5: 16%K_2O). The soil was pre-mixed with fertilizer two days before sowing. The pots were arranged in a randomized complete design with 6 replications for each genotype by water regime. In total, 108 pots were used in the present experiment.

Five days after sowing, seedlings were thinned to one plant per pot and water treatments; flooding as a control, well-irrigated (24% SMC) and drought (12%SMC) were applied. The soil water potentials of each regime were 0kPa, -1kPa and -53kPa under control treatment, 24% and 12% SMC treatments, respectively. For determination of soil water potential, the soil of each regime was well mixed with water in plastic pot, and the water potential of soil sample was measured using a watermark model 900M-Monitor (IRROMETER COMPANY, INC, RIVERSIDE, CA).

To avoid water evaporation from soil surface, each pot was covered by expanded polystyrene board with a small hole to allow seedling to grow. Water was added every 2 days to set the target SMC.

2.3. Measurements

Four weeks after sowing, seedlings were sampled. RL, RSA, RV, and RD were analyzed by using WinRHIZO (Regent Instrument Inc.). Leaf area (LA) was measured with an AAM-8 leaf area meter (Hayashi Denko Co. Ltd., Tokyo, Japan). Shoot dry weight (SDW) and root dry weight (RDW) were determined after drying in an oven at 80°C for three days. Water uptake (WU) rate was determined by weighing pots every two days and WU during the treatments and water use efficiency (WUE, total dry weight/WU) were calculated.

2.4. Data analysis

Analysis of variance was performed with different statistical tests in Unistat v. 5.6 software (Unistat Ltd., London, UK). Data were subjected to Tukey's test to compare mean values at the 5% level of significance.

3. RESULTS

3.1. Plant growth

3.1.1. Shoot dry weight

Figure 1 shows SDW of six varieties under three water regimes at the end of the experiment. Rayada showed the highest in SDW at control and well-irrigated treatments, followed by Sensho. SDW of Rayada, Sensho, IR24 and KD18 were not significant different between flooded and well-irrigated conditions. But those of Koshihikari and Beodien in well-irrigated condition were lower than those in flooded condition. SDW of KD18 and IR24 were lower value at all treatments than other varieties but at drought condition SDW of them were not severely affected compared with other varieties.

3.1.2. Root dry weight

Figure 2 shows RDW of six varieties under various water regimes. There were no significant different in RDW between control and 24% SMC treatments of Rayada, Sensho, KD18 and IR24. While as, those of Koshihikari and Beodien at 24% SMC treatment were significantly smaller than those at control treatment. RDW of Beodien had the highest value at flooded condition with 0.211 g/plant, followed by Sensho at the same treatment with 0.194 g/plant (Table 1). KD18 had the smallest in RDW at all treatments. Interestingly, KD18 and IR24 were smaller in RDW at all treatments than other varieties but those values had no change between flooded and drought treatment.

3.1.3. Total dry weight

TDW of six varieties under different water regimes is indicated in figure 3. TDW of almost all varieties did not significantly change between flooded and well-irrigated conditions except Beodien and Koshihikari. Rayada had the highest in TDW at control and 24% SMC treatments with 1.189 g/plant and 1.145 g/plant, respectively (Table 1). IR24 and KD18 were lower in TDW compared with other varieties at all treatments but there were a little decrease between flooded and drought treatments compared with other varieties.

3.1.4. Leaf area

Leaf area of six varieties under various water regimes are observed in Figure 4. LA of all varieties had significantly lower at drought treatment compared with other treatments. Rayada showed faster LA development than other varieties in control and 24% SMC treatments. LA of Rayada at control treatment had the highest value with 175.84cm^2 (Table 1). There was not significant change in LA between flooded and well-irrigated treatments of Rayada, Sensho, IR24 and KD18 except Beodien and Koshihikari. IR24 and KD18 had smaller in LA at all treatments than other varieties but those values were not severely affected by drought condition compared with other varieties.

3.1.5. Water uptake

Figure 5 shows WU of six varieties under three water regimes. WU of all varieties at drought condition had nearly the same value. WU of Rayada, Sensho, IR24 and KD18 did not significantly change between control and 24% SMC treatments. While that of Beodien and Koshihikari in well-irrigated treatment were smaller than those in control treatment. Rayada showed the highest value in WU at flooded and 24% SMC treatment with 295.60 g/plant and 287.16 g/plant, respectively, followed by Sensho at flooded and 24% SMC treatment with 257.30 g/plant and 282.07 g/plant, respectively (Table 2). WU of KD18 and IR24 were smaller value at all treatments than other varieties but it also was not severely affected by drought condition compared with other varieties.

3.1.6. Water use efficiency

WUE of six rice varieties under three water regimes are shown in figure 6. All varieties at drought condition had higher in WUE than those at flooded and well-irrigated conditions. WUE of almost varieties had no change between control and 24% SMC treatments except Koshihikari and Beodien. WUE of Beodien and Koshihikari were smaller in well-irrigated condition than those in flooded condition. Rayada had the highest in WUE at drought treatment, followed by Sensho at the same treatment.

3.2. Root morphological traits

Table 3 shows root morphological traits such as total root length, root surface area, root volume and rood average parameter of six varieties in seedling stage under various water regimes.

3.2.1. Total root length

RL of almost varieties tended to increase in the aerobic conditions (24% SMC and 12% SMC conditions) except Koshihikari. Koshihikari in aerobic conditions had a decrease of 18.82% and 21.40%, respectively, compared with flooded condition. Rayada had the highest RL at drought and well-irrigated conditions with 2237.76cm and 2096.31cm, respectively, followed by Sensho at drought and well-irrigated conditions with 1590.16cm and 1757.72cm, respectively. Interestingly, KD18 and IR24 had much higher RL at drought condition with 87.67% and 52.59%, respectively higher compared with flooded condition.

3.2.2. Root surface area

Except Koshihikari and Beodien, almost varieties were significantly increased in RSA at well-irrigated treatment as compared with its corresponding values at flooded treatment. RSA of almost varieties tended to increase at drought condition compared with flooded condition except Koshihikari. Koshihikari sharply decreased in aerobic conditions (well-irrigated and drought conditions) with 35.32% and 28.81% reduction, respectively. Rayada also was the highest in RSA at drought and well-irrigated conditions, followed by Sensho with 223.33cm^2 and 212.19cm^2 for Rayada, respectively and 164.58cm^2 and 194.40cm^2 for Sensho, respectively. Interestingly, RSA of KD18 and IR24 had much higher at drought condition than those at other treatments with 81.89% and 49.51%, respectively, as higher compared with flooded treatment.

3.2.3. Root volume

RV of Koshihikari and Beodien tended to decrease at aerobic conditions (24% and 12% SMC treatments). While as, other varieties at well-irrigated and drought treatments had higher in RV than those at control treatment. Interestingly, RV of KD18 and IR24 at 12% SMC treatment had markedly increased with 75.67% and 46.68%, respectively higher compared with those at control treatment. Sensho at well-irrigated condition and Rayada at flooded and well-irrigated conditions had the highest in RV with 1.716cm^3, 1.714cm^3 and 1.674cm^3, respectively.

3.2.4. Root average diameter

Table 3 indicates that RD of KD18 and IR24did not significantly change between flooded and aerobic conditions. Other varieties were significantly different in RD at drought condition compared with flooded condition. Beodien at flooded condition was the highest in RD with 0.39 mm, followed by Sensho at control and well-irrigated treatments with the same magnitude of 0.35mm. RD of Rayada, Sensho, KD18 and IR24 were not significantly different between well-irrigated and flooded conditions, contrary to those of Beodien and Koshihikari at well-irrigated condition were significantly lower than those at flooded condition.

4. DISCUSSION

In this experiment, Rayada, Sensho, IR24 and KD18 did not significantly change in SDW, RDW, TDW, LA, WU and WUE between flooded and well-irrigated conditions. While as, those of Koshikari and Beodien had smaller in well-irrigated treatment than those in control treatment (Fig 1-6). In addition, RL and RSA of almost varieties in aerobic conditions (24% SMC and 12% SMC conditions) tended to increase except Koshikari (Table 3). RL, RSA, RV, SDW, RDW, TDW, LA and WU of Koshihikari in aerobic conditions were lower than those in flooded condition. The results suggest that the root activity of Koshihikari decreased in aerobic conditions, especially in drought condition. Therefore, it might be difficult for the root systems of Koshihikari to exact enough soil water, explaining the significantly lower WU, TDW, LA under aerobic conditions. It was proved that Koshihikari might be affected severely by aerobic conditions, especially in drought condition. The results were conformed to the previous results (Matsuo and Mochizuki, 2009; Matsuo et al., 2010).

Among varieties used, Rayada showed the highest value in RL, RSA, RV, SDW, RDW, TDW, LA and WU, followed by Sensho (Fig 1-5). Moreover, Rayada had also the highest value in WUE in drought condition, followed by Sensho (Fig. 6). Therefore, in this study indicates that Rayada and Sensho can adapt well to aerobic rice systems (well-irrigated condition) and drought condition. So, Rayada and Sensho are promising cultivars for aerobic rice systems (Mastuo and Mochizuki, 2009).

KD18 and IR24 had smaller in SDW, RDW, TDW, LA, WU at all treatments compared with other varieties, these characters were not severely affected by drought compared with other varieties. Interestingly, RDW of KD18 and IR24 had no change between flooded and drought conditions. Furthermore, KD18 and IR24 had much higher in RL, RSA and RV at drought condition than those at other treatments with 87.67%, 81.89% and 75.67% for KD18, respectively and 52.59%, 49.51% and 46.68% for IR24, respectively higher compared with flooded condition (Table 3). It was proved that *indica* lowland rice varieties, KD18 and IR24 may be desirable drought tolerance varieties compared with *japonica* lowland rice varieties, Koshihikari.

Maya Matsunami et al. (2012) suggested that some lowland cultivars have high adaptability to upland conditions, as long as adequate soil moisture is maintained, comparable to that under flooded condition. In this experiment, three lowland cultivars Rayada, KD18, IR24 can be adapt well to well-irrigated condition.

Kondo (2000) reported that water uptake in rice declined markedly under severe drought stress compared with mild stress, whereas water uptake in maize was similar at two stress levels, possibly due to the deeper root growth that was observed in maize. In this study, WU of six varieties at drought condition were significantly decreased compared with flooded and well-irrigated conditions (Fig. 4).

Dry matter production ability of rice under drought condition was created by high ability of transpiration (= water uptake), but not by a high WUE (Kobata et al., 1996). Generally, deficient soil moisture causes a reduction of transpiration, resulting in an increase in WUE without increasing biomass production (Blum, 2005). Water uptake was the highest in control treatment of all varieties, so TDW of all varieties were also the highest in control treatment and the smallest in drought treatment. But WUE of six varieties were the highest value at drought condition. Following to Matsuo et al. (2010), the WUE values for Sensho and Beodien in water saving treatment were more than 20% higher than in well-irrigated treatment, whereas Koshihikari were only 86% of the values in water saving treatment. In this present study, WUE of Koshikari at well-irrigated treatment was less than that at drought condition. It proved that at early seedlings stage, WUE of Koshihikari tended to be higher in drought condition.

Water uptake by plants is strongly dependent on the morphological and physiological attributes of roots. Regarding rice root morphological, which is adaptable to flooded conditions, Yamauchi et al. (1988) speculated that those cultivars with a concentrated type of root system, which owns a large number of short individual crown roots, might be more adaptable to flooded condition, due to such a root system might be supplied adequate oxygen to the root apex to promote cell division. In this study, Rayada had the highest in RL, RSA, RV and WU, followed by Sensho. Furthermore, Rayada had also the highest in WUE at drought condition, followed by Sensho. So, they are suitable with aerobic conditions.

The present study showed that at drought stress significantly differed in root system development, as shown by RL, RSA, RV and RD (Table 3). The same results were found by ABD Allah, A.A., et al. (2010); Matsuo N. and Mochizuki T. (2009) and Matsuo et al. (2010) by using other genotypes. In this experiment, RL and RSA tended to increase in the aerobic conditions (24% and 12% SMC treatments) in almost varieties except Koshihikari. Among varieties used, Rayada had the highest value in RL, RSA and RV, followed by Sensho (Table 3). Osaki et al. (1997) suggested that high root activity secures a high photosynthetic rate by supplying a sufficient amount of nutrients to shoot, thus ensure high productivity. So, Rayada and Sensho can absorb more water to supply to shoot to produce biomass. In this study, SDW, TDW and LA of Rayada had the highest value, followed by Sensho (Fig. 1-3). Fast growth of SDW during the early growth stage may be a desirable trait under aerobic rice systems from the viewpoint of competition between rice plants and weeds.

Thick roots are also hypothesized to confer drought tolerance because root branching is related to root thickness (Fitter, 1991). Thick roots persist longer and produce more and larger root branch, thereby increase root length density and water uptake capacity (Ingram et al., 1994). Table 3 displays that RD of Rayada, Sensho, KD18, IR24 were not significantly different between control and well-irrigated treatment, so they could have the greater ability to extract water and keep water potential high by absorbing water due to they had high value of desirable root traits relating to drought avoidance mechanism. It proved that Rayada, Sensho, KD18 and IR24 can adapt with well-irrigated condition. Meanwhile, RD of Beodien and Koshihikari were markedly decreased by aerobic conditions relative to those in flooded condition. In addition, SDW, RDW, TDW, LA, WU and WUE of Koshihikari and Beodien in well-irrigated treatment were lower than those in control treatment. So, Koshihikari and Beodien were not suitable with aerobic conditions, even though in well-irrigated condition. Previous studies reported that *japonica* upland rice varieties had thicker roots than *indica* ones under aerobic conditions (Matsuo N. and Mochizuki T., 2009). In the present study, upland rice Beodien and Sensho had higher root average diameter than that in lowland rice at flooded and aerobic conditions and *japonica* upland rice (Sensho) was higher in RD than *indica* one (Beodien) under aerobic conditions.

5. CONCLUSION

SDW, RDW, TDW, LA, WU and WUE of Rayada, Sensho, KD18 and IR24 were not significant different between well-irrigated and flooded conditions. Those of Beodien and Koshihikari in well-irrigated condition were lower than those in flooded condition (Fig. 1-6).

In aerobic conditions (24% and 12% SMC treatments), RL and RSA of almost varieties tended to increase except Koshihikari. RL, RSA, RV of Koshihikari in aerobic conditions were lower than those in flooded condition (Table 3).

In conclusion, Rayada, Sensho, IR24 and KD18 can adapt with well-irrigated condition but Koshihikari and Beodien is not adaptable. In addition, Rayada and Sensho are suitable with aerobic rice systems. Interestingly, indica lowland rice varieties, KD18 and IR24 have desirable traits for drought tolerant varieties compared with japonica lowland rice variety, Koshihikari.

Further study is necessary to find differences in root characters such as root hydraulic conductance, aquaporin and physiological mechanism to respond water uptake and water use efficiency of rice under different water regimes.

Table 1. The effects of different water regimes on shoot dry weight (SDW), root dry weight (RDW), total dry weight (TDW) in seedling stage of some rice varieties

Variety	Treatment	Shoot dry weight (g/plant)	Root dry weight (g/plant)	Total dry weight (g/plant)	Leaf area (cm^{2})
Rayada	Control	1.006^{a}±0.125(-)	0.183^{a}±0.029(-)	1.189^{a}±0.148(-)	175.843^{a}±23.96(-)
	24% SMC	0.955^{a}±0.122(94.93%)	0.189^{a}±0.037(103.27%)	1.145^{a}±0.156(96.29%)	166.628^{a}±11.79(94.75%)
	12% SMC	0.386^{b}±0.035(38.36%)	0.134^{b}±0.011(73.22%)	0.521^{b}±0.042(43.81%)	64.110^{b}±3.78(36.45%)
Sensho	Control	0.807^{a}±0.09(-)	0.194^{a}±0.03(-)	1.000^{a}±0.11(-)	143.365^{a}±17.08(-)
	24% SMC	0.851^{a}±0.13(105.45%)	0.178^{a}±0.04(91.75%)	1.029^{a}±0.16(102.90%)	146.257^{a}±17.88(102.02%)
	12% SMC	0.343^{b}±0.07(40.31%)	0.127^{b}±0.03(65.46%)	0.493^{b}±0.08(49.30%)	76.605^{b}±16.01(53.43%)
KD18	Control	0.465^{a}±0.034(-)	0.079^{a}±0.012(-)	0.544^{a}±0.041(-)	86.988^{a}±4.47(-)
	24% SMC	0.428^{a}±0.081(92.04%)	0.069^{a}±0.016(87.34%)	0.498^{a}±0.084(91.54%)	78.478^{a}±8.2(90.22%)
	12% SMC	0.327^{b}±0.056(70.32%)	0.083^{a}±0.010(105.06%)	0.411^{b}±0.062(75.55%)	54.386^{b}±7.13(62.52%)
IR24	Control	0.537^{a}±0.108(-)	0.100^{a}±0.027(-)	0.637^{a}±0.131(-)	107.870^{a}±10.97(-)
	24% SMC	0.516^{a}±0.104(96.08%)	0.098^{a}±0.014(98%)	0.614^{a}±0.114(96.38%)	100.355^{a}±8.51(93.03%)
	12% SMC	0.276^{b}±0.060(53.48%)	0.093^{a}±0.019(93%)	0.369^{b}±0.079(57.92%)	46.626^{b}±4.53(43.22%)
Beodien	Control	0.836^{a}±0.11(-)	0.211^{a}±0.05(-)	1.046^{a}±0.15(-)	145.628^{a}±24.58(-)
	24% SMC	0.512^{b}±0.09(61.24%)	0.097^{b}±0.02(45.97%)	0.609^{b}±0.11(58.22%)	93.930^{b}±14.93(64.49%)
	12% SMC	0.366^{c}±0.04(43.78%)	0.099^{b}±0.01(46.92%)	0.443^{c}±0.05(42.35%)	68.012^{c}±5.83(46.70%)
Koshihikari	Control	0.852^{a}±0.11(-)	0.158^{a}±0.02(-)	1.010^{a}±0.12(-)	151.973^{a}±25.59(-)
	24% SMC	0.428^{b}±0.10(50.23%)	0.061^{b}±0.02(38.61%)	0.489^{b}±0.12(48.41%)	65.767^{b}±12.04(43.27%)
	12% SMC	0.305^{c}±0.04(35.79%)	0.051^{b}±0.01(32.27%)	0.356^{c}±0.05(35.25%)	50.770^{c}±8.04(33.40%)

Note: Mean value ± standard deviation

SMC means soil moisture content (w/w). Mean within a column followed by the same letter in each variety are not significantly different at $P<0.05$ by Tukey's Test (n=6)

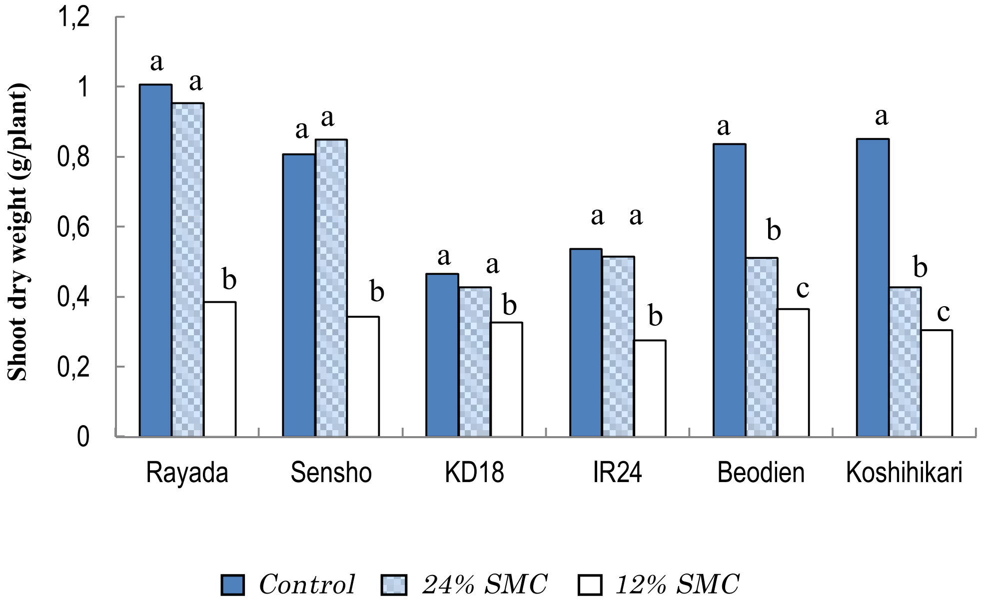

Fig. 1. The effects of different water regimes on shoot dry weight in seedling stage of some rice varieties

Note: SMC means soil moisture content (w/w). Bars with the same letter in each variety are not significantly different at $P<0.05$ by Tukey's test (n=6).

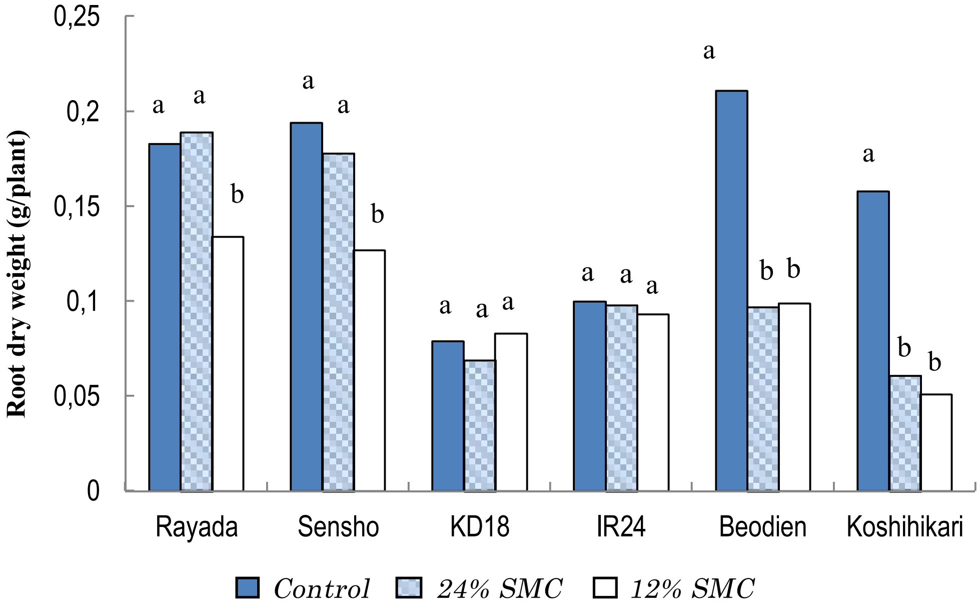

Fig. 2. The effects of different water regimes on root dry weight in seedling stage of some rice varieties

Note: SMC means soil moisture content (w/w). Bars with the same letter in each variety are not significantly different at P<0.05 by Tukey's test (n=6).

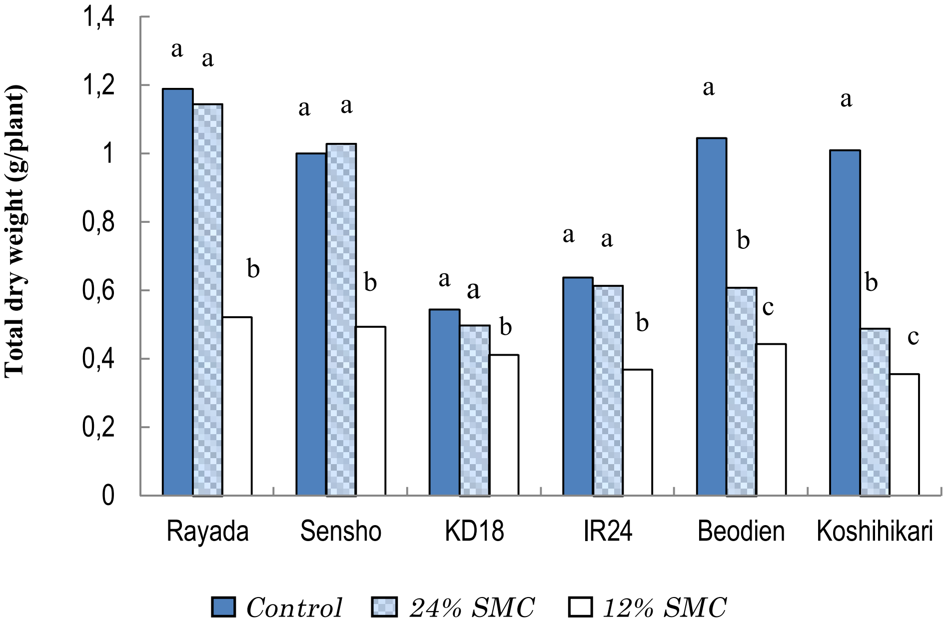

Fig. 3. The effects of different water regimes on total dry weight in seedling stage of some rice varieties

Note: SMC means soil moisture content (w/w). Bars with the same letter in each variety are not significantly different at P<0.05 by Tukey's test (n=6)

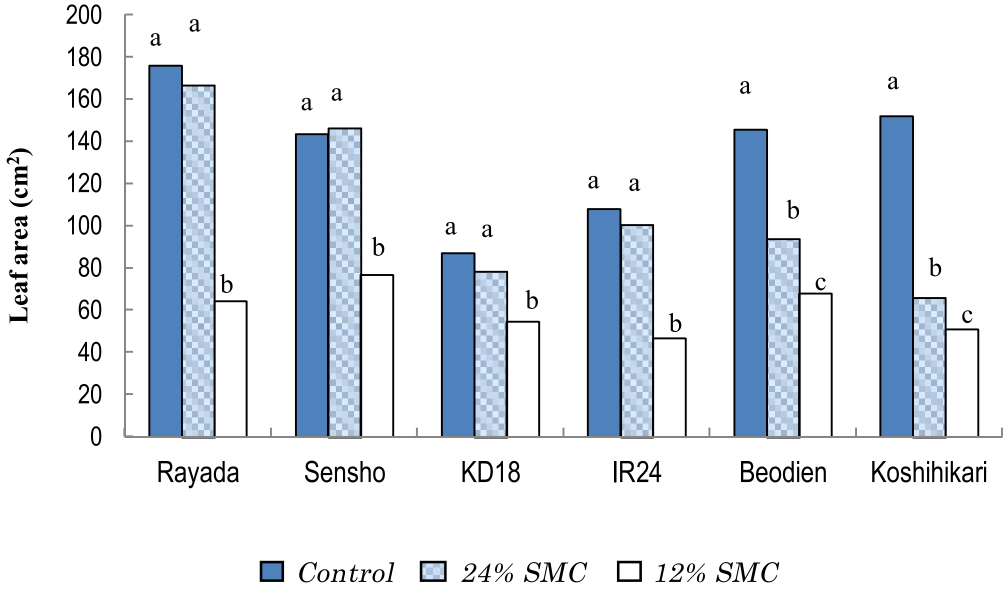

Fig. 4. The effects of different water regimes on leaf area in seedling stage of some rice varieties

Note: SMC means soil moisture content (w/w). Bars with the same letter in each variety are not significantly different at P<0.05 by Tukey's test (n=6).

Table 2. The effects of different water regimes on water use (WU) and water use efficiency (WUE) in seedling stage of some rice varieties

Variety	Treatment	Water uptake (g/plant)	Water use efficiency (g DW/g H_2O)
Rayada	Control	$295.60^{a}\pm45.20$(-)	$0.00402^{b}\pm0.0002$(-)
	24% SMC	$287.16^{a}\pm35.60$(97.14%)	$0.00400^{b}\pm0.0002$(99.50%)
	12% SMC	$89.55^{b}\pm6.45$(30.29%)	$0.00583^{a}\pm0.0004$(145.02%)
Sensho	Control	$257.30^{a}\pm23.99$(-)	$0.00388^{b}\pm0.0002$(-)
	24% SMC	$282.07^{a}\pm35.53$(109.63%)	$0.00364^{b}\pm0.0002$(97.37%)
	12% SMC	$90.11^{b}\pm18.81$(35.02%)	$0.00553^{a}\pm0.0006$(147.37%)
KD18	Control	$152.42^{a}\pm13.92$(-)	$0.00358^{b}\pm0.0002$(-)
	24%	$141.89^{a}\pm22.16$(93.09%)	$0.00355^{b}\pm0.0006$(99.16%)
	12%	$79.85^{b}\pm8.08$(52.38%)	$0.00513^{a}\pm0.0006$(143.29%)
IR24	Control	$188.45^{a}\pm31.02$(-)	$0.00336^{b}\pm0.0002$(-)
	24% SMC	$185.52^{a}\pm18.12$(100.03%)	$0.00331^{b}\pm0.00039$(98.51%)
	12% SMC	$78.45^{b}\pm12.94$(41.62%)	$0.00468^{a}\pm0.00037$(139.28%)
Beodien	Control	$244.51^{a}\pm34.01$(-)	$0.00428^{b}\pm0.0002$(-)
	24% SMC	$175.41^{b}\pm26.36$(71.74%)	$0.00346^{c}\pm0.0001$(83.33%)
	12% SMC	$85.78^{c}\pm10.04$(35.08%)	$0.00516^{a}\pm0.0002$(123.80%)
Koshihikari	Control	$237.61^{a}\pm25.5$(-)	$0.00424^{b}\pm0.0002$(-)
	24% SMC	$134.23^{b}\pm26.58$(56.49%)	$0.00361^{c}\pm0.0003$(83.72%)
	12% SMC	$71.33^{c}\pm10.07$(26.07%)	$0.00499^{a}\pm0.0002$(116.27%)

Note: Mean value ± standard deviation
SMC means soil moisture content (w/w). Mean within a column followed by the same letter in each variety are not significantly different at P<0.05 by Tukey's Test (n=6)

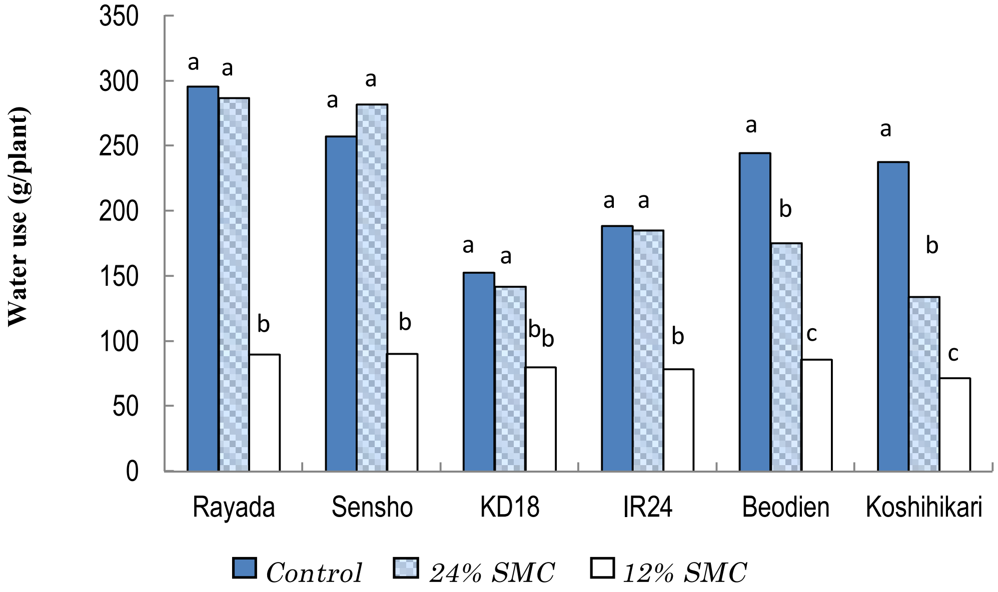

Fig. 5. The effects of different water regimes on water use in seedling stage of some rice varieties

Note: SMC means soil moisture content (w/w). Bars with the same letter in each variety are not significantly different at P<0.05 by Tukey's test (n=6).

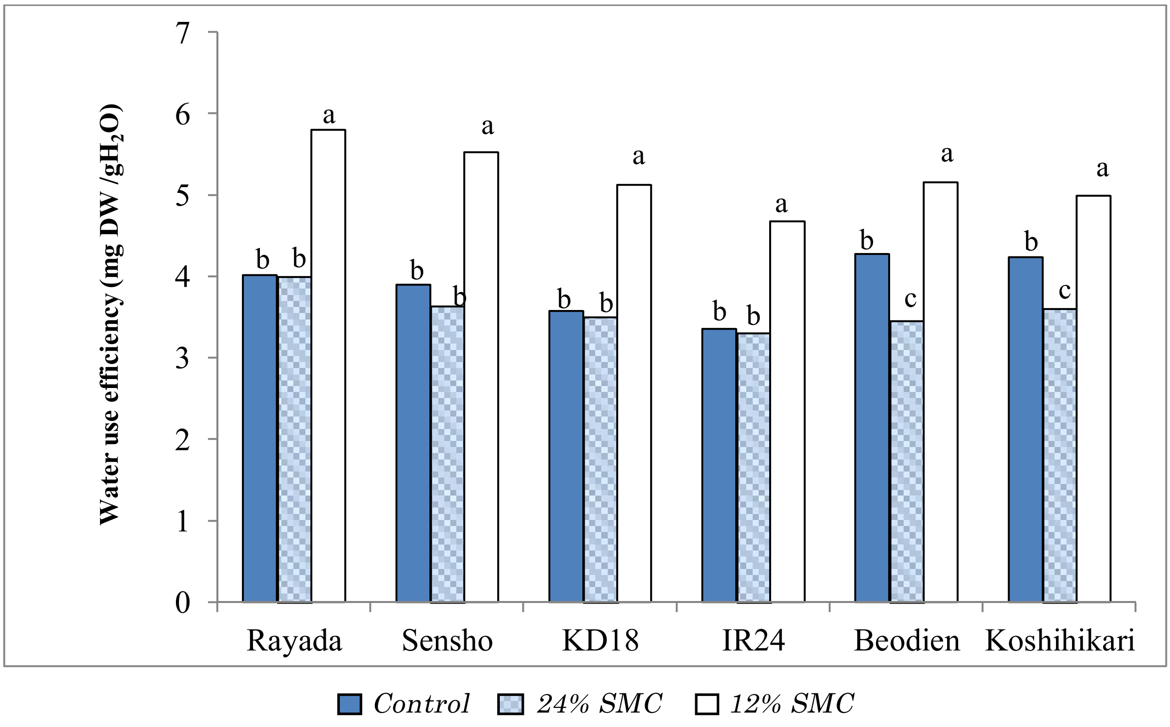

Fig. 6. The effects of different water regimes on water use efficiency in seedling stage of some rice varieties

Note: SMC means soil moisture content (w/w). Bars with the same letter in each variety are not significantly different at P<0.05 by Tukey's test (n=6).

Table 3. The effects of different water regimes on total root length (RL), root surface area (RSA), root volume (RV) and root average diameter (RD) in seedling stage of some rice varieties

Variety	Treatment	Length(cm)	Area (cm^2)	Volume (cm^3)	Diameter (mm)
Rayada	Control	1621.62^{c} ± 101.67(-)	162.79^{b}±12.75(-)	1.31^{b}±0.18(-)	0.32^{a}±0.025(-)
	24% SMC	2096.31^{b} ± 164.74(129.27%)	212.20^{a}±26.10(130.34%)	1.71^{a}±0.30(131.24%)	0.32^{a}±0.020(100.63%)
	12% SMC	2379.76^{a}±219.49(146.75%)	223.33^{a}±25.70(137.19%)	1.67^{a}±0.26(128.17%)	0.29^{b}±0.018(93.12%)
Sensho	Control	1348.55^{c}±101.61(-)	150.01^{b}±10.58(-)	1.34^{b}±0.18(-)	0.35^{a}±0.03(-)
	24% SMC	1757.72^{a}±230.96(130.34%)	194.40^{a}±20.06(129.59%)	1.72^{a}±0.28(128.44%)	0.35^{a}±0.02(100%)
	12% SMC	1590.16^{b}±167.08(117.92%)	164.57^{b}±26.93(109.70%)	1.36^{b}±0.31(101.79%)	0.33^{b}±0.02(92.09%)
KD18	Control	910.92^{b}±62.30(-)	87.22^{b}±5.65(-)	0.67^{b}±0.07(-)	0.30^{a}±0.018(-)
	24% SMC	1015.84 ^{b}±264.04(111.52%)	93.22^{b}±23.77(106.87%)	0.68^{b}±0.18(102.40%)	0.29^{a}±0.014(96.71%)
	12% SMC	1709.55^{a}±75.57(187.67%)	158.29^{a}±11.03(181.49%)	1.17^{a}±0.14(175.67%)	0.29^{a}±0.017(96.71%)
IR24	Control	1185.29^{c}±177.44(-)	113.92^{c}±21.64(-)	0.87^{b}±0.21(-)	0.30^{a}±0.024(-)
	24% SMC	1452.79^{b}±157.89(122.56%)	139.19^{b}±11.47(122.18%)	1.06^{ab}±0.09(121.73%)	0.30^{a}±0.016(100.65%)
	12% SMC	1808.74^{a}±298.89(152.59%)	170.33^{a}±35.36(149.51%)	1.28^{a}±0.32(146.68%)	0.29^{a}±0.018(98.02%)
Beodien	Control	1227.97^{b} ± 211.80(-)	153.18^{ab}±33.17(-)	1.53^{a}±0.42(-)	0.39^{a}±0.03(-)
	24% SMC	1389.67^{b} ± 196.08(113.17%)	131.64^{b}±17.59(85.94%)	0.99^{b}±0.15(65.27%)	0.30^{b}±0.02(76.65%)
	12% SMC	1753.87^{a} ± 270.02(142.82%)	167.54^{a}±23.54(109.37%)	1.27^{a}±0.16(83.48%)	0.30^{b}±0.01(77.16%)
Koshihikari	Control	1284.09^{a} ± 194.08(-)	136.98^{a}±23.57(-)	1.17^{a}±0.24(-)	0.34^{a}±0.02(-)
	24% SMC	1042.37^{b} ± 104.62(81.18%)	88.59^{b}±22.23(64.68%)	0.60^{b}±0.18(51.54%)	0.27^{c}±0.02(79.41%)
	12% SMC	1008.15^{b} ± 131.58(78.51%)	97.52^{b}±15.02(71.19%)	0.75 ^{b}±0.16(64.55%)	0.31^{b}±0.02(91.17%)

Note: Mean value ± standard deviation

SMC means soil moisture content (w/w). Mean within a column followed by the same letter in each variety are not significantly different at $P<0.05$ by Tukey's Test (n=6)

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