Effects of irrigation and weed-control methods on growth of weed and rice

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Abstract: A field experiment was conducted to study the effects of weeds control methods and an irrigation model on rice growth as well as water consumption and weed quantity in the paddy field. In conventional paddy rice production, one of the most important irrigated crops, a significant amount of irrigation water is lost due to percolation and evaporation. A new irrigation model called the Rain-Catching and Controlled Irrigation (RCCI) model has been developed as a viable water-saving technology in the production of paddy rice. In this study the performance of the RCCI model has been analyzed under mulching, hand weeding and weedy conditions in Jiangsu Province of China. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications and nine treatments. The three replicates consisted of three water management regimes: high dry high flooding (HD-HF), high dry low flooding (HD-LF), and shallow and frequent irrigation (SF) water treatment. The RCCI model was adopted in HD-HF and HD-LF while Flooding Irrigation (CFI) was adopted in SF as a control. The nine treatments were equally divided under mulching, hand weeding and weedy conditions. The lowest and maximum irrigation water delivery was 244.86 mm in mulching and 429.22 mm in hand weeding, respectively at HD-HF. And the lowest and maximum irrigation water delivery was 300.1 mm in the mulching field and 680.72 mm under hand weeding, respectively at HD-LF. The Nanjing 44 rice variety was used. It was observed that weed density and dry weight were significantly influenced by the amount of irrigation water in all the mulching, hand weeding and weedy plots. Considering yield and the number of irrigations, the RCCI model produced better results than CFI. Mulching under RCCI was an effective method to control weeds and reduce labor cost. In addition, mulching decreases the use of herbicides and the risk of pollution. On the other hand, mulching could improve yield and save water.

Keywords: irrigation, weed control, mulching, hand weeding, RCCI, weed population, agronomy traits, paddy rice
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1 Introduction

Many countries in the world are concerned with environmental pollution associated with industrial development, population growth, and rises in the living standards. The ever-increasing world population needs sound technology to guarantee adequate food supply that can only be achieved through greater agricultural productivity, but the higher yields cannot be obtained without effective weed management even under ideal management practices[1]. Experimental data indicate that as much as 85% of yield could be lost due to weeds[2]. About 8 000 species are said to behave as weeds in agriculture, out of which 250-300 are seriously harmful weed species and the rice losses attributed to them run into billions of dollars[1,3,4].

Rice is the seed of the monocot plants *Oryza sativa* (Asian rice) or *Oryza glaberrima* (African rice). As cereal grain, it is the most important staple food for a

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large part of the world's human population, especially in Asia. It is the most important cereal crop but its productivity is affected by climatic, biotic, edaphic and economic factors. Weeds cause enormous reduction in crop yields, wastage of resources and human energy and also pose health hazards to human beings. Weeds are a major limiting factor for the growth and yield of paddy. They usually grow faster than rice plants and absorb available water and nutrient earlier than paddy crops, suppressing crop growth in the process. There is a strong interest in developing alternative methods of weed control in organic agriculture[5].

Weed species respond differently to changing water regimes[6], and post-planting soil moisture status is a major influential factor for weed flora composition[7,8]. In rice culture, water and weeds are often considered to be closely interlinked. For example, the dominance of grasses is favored by unsaturated conditions, whereas (aquatic) broadleaves and sedges grow rapidly when soil is submerged with water[6]. Under aerobic soil conditions, weed diversity is much higher compared to that under saturated or flooded conditions[8].

Mulching is used in agriculture throughout the world to control weeds[9]. Mulches can be very effective against weeds, especially annual weeds. Mulches work primarily by depriving young weed seedlings of vital sunlight. Mulching can decrease the occurrence of weeds by blocking light and release of allelopathic substance. Organic mulches are more popular in the cropping systems, as they can suppress weeds, while reducing soil tillage for weed control, under any tillage system implemented[10]. Residue of small grains has been shown to inhibit weed emergence and growth in cropping systems by allelopathy[11,12]. Since weed seed germination is affected by soil moisture and temperature, mulch does not only suppress weeds, but also maintains soil moisture at higher levels compared to unmulched soil[13,14]. Crop residues overspread on soil surface decrease soil temperature in the hot season and maintain it in autumn[15,16]. The reduction in paddy yield due to weed composition ranges from 9% to 51%[17]. Grain yield will be drastically reduced if paddy is not weeded out during early growth stages[18].

Proper water management is the most important factor in controlling weeds during rice production as well as hand weeding. Mulching was used as a method to control weeds in dry land. Research on wet land especially in paddy rice field is insufficient, especially in Tanzania. In this study a new irrigation model: the Rain-Catching and Controlled Irrigation Model (RCCI)[19] was used. The study was undertaken to assess the effects of the RCCI model on weed growth, agronomy traits of rice, and water control under mulching, hand weeding, and unweeding methods. Preliminary research showed that the RCCI model under mulching saved water, reduced labor cost, prevented herbicide-related environmental pollution, and increased yield.

2 Materials and methods

2.1 Experiment site and field soil conditions

The experiment was conducted from May to September 2012 at the Water Saving Park Agricultural Experimental Farm of Hohai University in Nanjing, China. The park is located at 31°95′N, 118°83′E with a humid subtropical climate and is under the influence of the East Asia Monsoon. The annual mean temperature is 15.5°C with monthly means ranging from 2.4 °C to 27.8°C; the maximum temperature of the area is 43.0°C while the minimum is −16.9°C. The average annual rainfall is 1 062 mm. The soil at the experimental site is clayey loam with the field capacity of 29.3%. The other physical and chemical properties of the field soil were shown in Table 1.

Table 1 Soil physical and chemical properties

Soil depth/cm	Soil texture	Organic matter/mg·kg^{-1}	pH value	Total phosphorus/mg·kg^{-1}	Available P/mg·kg^{-1}	Total N/%	Available nitrogen/mg·kg^{-1}
0-20	Clay	8.06	8.06	330.9	10.13	0.1	65

2.2 Plant material and growth condition

A local high-yielded rice variety, Nanjing 44 (*Oryza Sativa* L. cv. Nanjing 44) was used in this research. The whole growing period of Nanjing 44 is around 120 days and it has an average height of 100 cm, large panicle (168-243) solid grains per panicle and the weight of 1 000 grains is around 27 g.

2.3 Experimental design and water management

The experiment was laid out in Randomized Complete Block Design (RCBD), consisting of nine treatments with three replications. There were three water management regimes – high dry high flooding (HD-HF) water treatments, high dry low flooding (HD-LF) water treatments and shallow and frequent irrigation (SF) water treatments under each weeds control method, including mulching, hand weeding and weedy plots, as shown in Table 2. The average plot size was 20 m^2 (2.5 m × 8 m). Plastic lining in the bunds was 45 cm deep to prevent lateral flow of water between the plots. In late season, wheat straw was applied at 7 500 kg/ha in dry weight after transplanting. Seedlings grown in the nursery for a month were then transplanted at a density of 25 hills/m^2 and two plants per hill. Fertilizer at the rate of 265-80-75 kg /ha (NPK) was applied in three splits. Nitrogenous fertilizer was given in three splits, first at seeding, second at transplanting and third at the panicle initiation stage as basal fertilizer after transplanting and thoroughly incorporated in the soils by hand. Irrigation water was pumped from the pond nearby and induced through pipes to the experimental plots and the amount of irrigation water was measured by a water-meter, following local farming practices without spraying insecticides or herbicides.

Table 2 Experimental design of controllable irrigation (unit: mm)

Regime	Seedling	Irrigation quantity at different growth stages					
		Early tillering	Later tillering	Elongation	Heading	Milky	Ripening
SF	10-30-70	0-30-70	0-30-90	0-30-120	0-30-100	0-30-60	70%-80%
HD-LF	10-30-70	80%-100%-80	70%-100%-100	70%-100%-150	80%-100%-150	80%-100%-80	70%-80%
HD-HF	10-30-70	80%-100%-100	70%-100%-120	70%-100%-200	80%-100%-200	80%-100%-80	70%-80%

Note: The three data (mm), for example in 10-30-70 respectively, means the lower limit of irrigation, upper limit of irrigation and the maximum water-catching depth after rain, respectively and "%" means that the percentage of average moisture content of the soil was accounted for by the total saturated water content at 30 cm soil depth.

The data on weed infestation and weed density were collected from each unit plot at 30, 60, 90 day after transplanting (DAT). A quadrate of 0.25 m^2 was placed randomly at three different spots outside an area of 6 m^2 in the middle of the plot. To record weed dry weight, weeds were cut at ground level, washed with water, the fresh weeds were subjected to the oven temperature at 105°C within 5 minutes to kill the weeds. They were subsequently dried at 70°C for 72 h and then weighed. The infesting species of weeds within each quadrate were identified and their number was counted species-wise. The average number of three replications was then multiplied by 4 to obtain the weed density per m^2. An area of 4 m^2 including the crop sampling zone was harvested for measurements of grain and straw yields. Weed control efficiency (WCE), weed index, and relative dry weight (RDW) were computed using the following formulae:

$$\text{Weed control efficiency } \% = \frac{\text{Weed population in control plots} - \text{Weed population in treated plots}}{\text{Weed population in control plots}} \times 100 \qquad (1)$$ [17]

$$\text{Weed index } \% = \frac{\text{Grain yield in weed free plots} - \text{Grain yield in treated plots}}{\text{Grain yield in treated plots}} \times 100 \qquad (2)$$ [20]

$$\text{RDW } \% = \frac{\text{Dry weight of a given species } (\text{g} \cdot \text{m}^{-2})}{\text{Total dry weight } (\text{g} \cdot \text{m}^{-2})} \times 100 \qquad (3)$$ [21]

At physiological maturity, the harvested crops were threshed, cleaned, dried, weighed and different parameters like plant height, effective tillers per hill, filled grains per panicle, unfilled grains per panicle,1 000-grains weight (g); straw yield (kg/ha); and grain yield (kg/ha) were taken. The paddy crop was harvested in the third week of September. The samples were collected from four sampling areas of 0.5 m × 0.5 m (total 1 m^2 for four samples) in each plot. In addition, the grain yield (adjusted to 14% moisture content) was determined at harvest using the yield components obtained[34].

Grain yield = (number of panicles per area × Number of spikelets per panicle × % grain filling × 1000 grain weight (4)

Harvest index (HI)% = (Grain yield)/biological yield)×100 (5)

where,

Biological yield = sum of grain yield plus straw yield (6)

Irrigation water use indices: Plastic pots of size 80 cm diameter and 60 cm height were buried in each plot to measure evapotranspiration (ET). The soil density and moisture in these pots were kept the same as that in fields.

Soil water content measurement: Volumetric soil water content was measured using frequency domain reflectometer probes (MP-917), which were embedded to a depth of 20 cm in the soil. Four probes were used as replicates in each plot.

The Crop Water Indices (CWI) and Irrigation Water Use Indices (IWUI) were calculated by using the following formula:

$$\text{Crop water use indices (CWUI) (kg} \cdot \text{mm}^{-1}) = \frac{Y}{ET} \quad (7)$$

where, Y is the yield of irrigated plants (kg), and ET is the evapotranspiration from seedling to the harvest.

Irrigation water use indices (IWUI):

$$\text{IWUI (kg} \cdot \text{ML}^{-1}) = \frac{\text{Yield (tonnes)}}{\text{Irrigation water applied (ML)}} \quad (8)$$

where, ML: Mega Liter = 1 000 m^3.

Statistical analysis: The data were analyzed using one way analysis of variance (one way ANOVA) to compare averages of quantitative parameters related to the effects of the different treatments. All data were subjected to statistical analysis and the Duncan's Multiple Range Test (DMRT) at the 5% level of significance was employed to compare the differences among treatments' means[22]. The analysis and construction of the graphs were carried out using SPSS 16.0 for windows (SPSS Inc, Chicago, IL, USA) and Microsoft Excel (2010), respectively.

3 Results and discussion

The results showed that the total weed density and dry weight of hand weeded and weedy check were higher than those treated with mulch. The major weeds associated in the field were *Monochoria vaginalis, Cyperus iria, Cyperus rotundus, Cyperus difformis, Alternanthera sessilis* (L.), *Polygonum Lapathifolium, Echinochloa colonum, Fimbristylis miliacea.* Eight different weed species belonging to five families were found to have infested the experimental crop. Among those, five were sedge, one was grass and two were broad-leaved. Sedge weeds highly dominated the water regime treatments especially at 30, 60 and 90 DAT in both planting season, followed by broadleaved; while the number of grasses was found to be significantly less under water regime treatments in all the planting seasons. The most common weed species throughout the growing seasons were *Cyperus difformis, Monochoria vaginalis*, and *Fimbristylis miliacea*. The mulch and hand weed treatments resulted in lower weed density than the weedy check. The weedy check plot at HD-HF treatment had as much higher weeds as up to 62 plants/m^2 at 30 DAT, 110 plants/m^2 at 60 DAT and 139 plants/m^2 at 90 DAT. Mulching was found better to control early flush of weeds while hand weeding might also be required to control the weeds, particularly for the most rapid tillering stage of paddy rice crops. As a result of severe water level fluctuation, the submerged aquatic weed became dominant because it might have a good tolerance, especially, near the littoral zone. These aquatic weeds (as mentioned above) might have been responsible for the lower quantity as well as quality of water results. They cause taste and odour problems and also increase biological oxygen demand because of organic loading[23].

However, mulching played an important role in the control of early flush weeds in cropping system at 30 DAT and 60 DAT because it might have deprived young weed seedlings of vital sunlight. Mulching could have also decreased the occurrence of weeds by blocking light and the release of allelopathic substances. Rice straw could be used for mulching and this prevents weed growth and supplies organic matter for heterotrophic N-fixing microorganisms, which could be utilized by succeeding crops. However, hand weeding is also required to control weeds, particularly at the most rapid tillering stage of rice crop. The amount of water also influences the number of weeds in the field as shown in Table 3, Table 4 and Table 5.

Weed dry weight was significantly influenced by weed control treatments and the amount of water. Dry weights of weeds were highest in the weedy plots at 30, 60 and 90 DAT at 30.7, 194.4 and 285 g/m^2, respectively. However, hand weeding also controlled weeds to a great level. The weed population was less in all treatments except weedy control (Table 3, Table 4 and Table 5). Singh and Kumar[20] also reported that the maximum weed dry weight was recorded in the unweeded control which was significantly higher compared to other weed control treatments. The weed population in weed control was higher than in all the other treatments. The number of weed species also increased. The dry weight of weed species increased with increasing crop-weed competition period.

The weed control efficiency was found highest (93.1%) in mulching at SF and hand weeded plots was (63.8%) at SF during the 30 DAT (Table 3), while at 60 DAT (Table 4) the weed control efficiency was found highest (75.4%) in mulching at HD-HF and hand weeded plots weeded was (60.9%) at HD-HF and at 90 DAT (Table 5) 64.8% was highest in mulching at HD-LF and hand weeding plots was (67.4%) at HD-HF. The weed indexes increased with the duration of crop weed competition and also control practices. The maximum weed indexes were 80.9% and 16.7% in weedy check and mulching, respectively (Table 5).

Table 3 Weed species, weed density (No./m^2), weed dry weight (g/m^2), relative dry weight (RDW) % and weed control efficiency (WCE) % in the field 30 DAT

Weed species		Treatments								
		Mulching			Hand weeding			Weedy check		
		SF	HD-LF	HD-HF	SF	HD-LF	HD-HF	SF	HD-LF	HD-HF
Cyperus rotundus	A	0.0^{c}	0.0^{c}	0.0^{c}	1.9^{b}	1.9^{b}	2.1^{b}	3.3^{a}	3.2^{a}	3.0^{a}
	B	0^{f}	0^{f}	0^{f}	2^{e}	3^{de}	4^{cd}	7^{a}	6^{ab}	5^{bc}
	C	0.0^{f}	0.0^{f}	0.0^{f}	14.1^{c}	17.4^{a}	15^{b}	11.1^{d}	11.6^{d}	9.8^{e}
Cyperus iris	A	0.0^{e}	0.0^{e}	0.0^{e}	1.7^{c}	1.1^{d}	1.5^{cd}	2.7^{a}	2.2^{b}	2.8^{a}
	B	0^{d}	0^{d}	0^{d}	3^{bc}	2^{c}	3^{bc}	6^{a}	4^{b}	6^{a}
	C	0.0^{f}	0.0^{f}	0.0^{f}	12.6^{a}	10.1^{c}	10.7^{b}	9.1^{d}	8.0^{e}	9.1^{d}
Cyperus difformis	A	2.4^{c}	1.7^{c}	1.9^{c}	2.1^{c}	1.7^{c}	2.4^{c}	8.9^{a}	5.7^{b}	9.3^{a}
	B	1^{d}	1^{d}	1^{d}	4^{c}	4^{c}	6^{c}	16^{a}	10^{b}	18^{a}
	C	52.2^{a}	50.0^{a}	24.7^{bc}	15.6^{d}	15.6^{d}	7.1^{d}	30.1^{b}	20.7^{cd}	30.3^{b}
Alternanthera sessilis	A	0.0^{d}	0.8^{c}	0.0^{d}	1.1^{cd}	1.3^{bcd}	0.9^{c}	2.5^{a}	2.0^{ab}	1.7^{bc}
	B	0^{b}	1^{b}	0^{b}	2^{b}	2^{b}	2^{b}	6^{a}	5^{a}	5^{a}
	C	0.0^{f}	23.5^{a}	0.0^{f}	8.1^{c}	11.9^{b}	6.4^{de}	8.4^{c}	7.3^{cd}	5.5^{e}
Polygonum Lapathifolium	A	0.0^{d}	0.0^{d}	1.2^{c}	2.2^{b}	0.9^{c}	2.6^{b}	2.8^{b}	3.9^{a}	3.8^{a}
	B	0^{f}	0^{f}	1^{e}	3^{d}	1^{e}	3^{d}	4^{c}	9^{a}	7^{b}
	C	0.0^{g}	0.0^{g}	15.6^{b}	16.3^{b}	8.3^{f}	18.6^{a}	9.5^{e}	14.2^{e}	12.4^{d}
Monochoria vaginalis	A	1.6^{b}	0.0^{d}	1.3^{bc}	1.4^{bc}	0.8^{c}	1.7^{b}	3.4^{a}	3.8^{a}	4.0^{a}
	B	1^{cd}	0^{d}	1^{cd}	2^{c}	2^{c}	2^{c}	5^{b}	6^{ab}	7^{a}
	C	34.8^{a}	0.0^{e}	16.9^{b}	10.4^{cd}	7.3^{d}	12.1^{c}	11.5^{c}	13.8^{bc}	13.0^{c}
Echnolochloa colona	A	0.0^{f}	0.0^{f}	2.6^{cd}	2.0^{de}	2.3^{cde}	1.5^{cd}	3.1^{bc}	4.9^{a}	3.7^{b}
	B	0^{d}	0^{d}	1^{c}	1^{c}	1^{c}	1^{c}	2^{b}	4^{a}	4^{a}
	C	0.0^{f}	0.0^{f}	33.8^{a}	14.8^{d}	21.1^{b}	10.7^{e}	10.5^{e}	17.8^{c}	12.1^{e}
Fimbristylis miliacea	A	0.6^{f}	0.9^{def}	0.7^{ef}	1.1^{de}	0.9^{def}	1.3^{d}	2.9^{a}	1.8^{c}	2.4^{b}
	B	1^{d}	1^{d}	1^{d}	2^{d}	2^{d}	4^{c}	8^{a}	5^{bc}	6^{b}
	C	13.0^{b}	26.5^{a}	9.1^{cd}	8.1^{de}	8.3^{de}	9.3^{cd}	9.8^{c}	6.5^{f}	7.8^{e}
Other broads leaf	B	1^{b}	1^{b}	1^{b}	2^{b}	2^{b}	2^{b}	4^{a}	5^{a}	4^{a}
Total weed density plants (m^{-2})		4^{h}	4^{h}	6^{g}	21^{e}	19^{f}	27^{d}	58^{b}	54^{c}	62^{a}
Total dry weight (g·m^{-2})		4.6^{g}	3.4^{h}	7.7^{f}	13.5^{d}	10.9^{e}	14^{d}	29.6^{b}	27.5^{c}	30.7^{a}
WCE (%)		93.1^{b}	92.6^{c}	90.3^{d}	63.8^{f}	64.8^{e}	56.4^{g}	0.0^{a}	0.0^{a}	0.0^{a}

Note: In the column, averages followed by the common letter(s) are not significantly different at level of $P\leq5\%$ according to Duncan's Multiple Range Test.

A = Weed dry weight of given species (g/m^2); B = Weeds (No./m^2); C = Relative dry weight (RDW) %; WCE = Weed control efficiency (%).

Table 4 Weed species, weed density (No./m^2), weed dry weight (RDW) % and weed control efficiency (WCE) % in the field 60 DAT

Weed species		Treatments								
		Mulching			Hand weeding			Weedy check		
		SF	HD-LF	HD-HF	SF	HD-LF	HD-HF	SF	HD-LF	HD-HF
Cyperus rotundus	A	5.8^{f}	5.1^{f}	10.2^{e}	19.3^{c}	17.1^{d}	11.3^{e}	40.1^{a}	34.8^{b}	34.2^{b}
	B	2^{cd}	1^{c}	2^{cd}	5^{b}	3^{c}	2^{cd}	8^{a}	6^{b}	6^{b}
	C	14.7^{d}	12.3^{e}	22.7^{b}	24.1^{a}	23.1^{ab}	14.4^{d}	22.4^{b}	18.3^{c}	17.6^{c}
Cyperus iris	A	5.2^{g}	4.8^{g}	7.3^{e}	7.5^{e}	6.2^{f}	9.8^{d}	41.7^{b}	40.7^{c}	53.9^{a}
	B	1^{e}	1^{e}	2^{d}	2^{d}	1^{e}	2^{d}	10^{b}	8^{c}	16^{a}
	C	13.2^{e}	11.6^{f}	16.3^{d}	9.4^{g}	8.4^{g}	12.5^{ef}	23.3^{b}	21.4^{c}	27.7^{a}
Cyperus difformis	A	5.1^{h}	3.2^{i}	6.7^{g}	10.7^{f}	12.1^{e}	16.9^{c}	22.3^{b}	15.5^{d}	25.8^{a}
	B	8^{ef}	6^{f}	11^{e}	18^{cd}	17^{d}	21^{c}	31^{b}	28^{b}	36^{a}
	C	12.9^{de}	7.7^{f}	14.9^{c}	13.4^{d}	16.4^{b}	21.6^{a}	12.4^{e}	8.1^{f}	13.3^{d}
Alternanthera sessilis	A	5.3^{f}	3.7^{g}	1.6^{h}	11.4^{d}	3.5^{g}	6.2^{e}	18.6^{a}	13.2^{c}	17.0^{b}
	B	3^{e}	2^{ef}	1^{f}	5^{d}	2^{ef}	3^{e}	8^{b}	6^{c}	9^{a}
	C	13.4^{b}	9.0^{d}	3.7^{i}	14.3^{a}	4.7^{h}	7.9^{f}	10.4^{c}	6.9^{g}	8.7^{e}
Polygonum Lapathifolium	A	5.1^{e}	3.5^{f}	6.9^{d}	8.3^{d}	13.7^{b}	13.0^{bc}	17.7^{a}	11.8^{c}	13.6^{b}
	B	2^{d}	1^{e}	3^{c}	2^{d}	5^{b}	4^{bc}	6^{a}	4^{bc}	4^{bc}
	C	12.9^{d}	8.5^{f}	15.4^{c}	10.4^{e}	18.5^{a}	16.6^{b}	9.9^{e}	6.2^{g}	7.0^{g}
Monochoria vaginalis	A	3.8^{f}	7.6^{d}	2.3^{g}	6.9^{de}	6.6^{e}	7.1^{de}	14.9^{b}	20.4^{a}	12.5^{c}
	B	2^{d}	4^{c}	2^{d}	3^{cd}	3^{cd}	3^{cd}	10^{b}	13^{a}	11^{b}
	C	9.6^{c}	18.4^{a}	5.1^{f}	8.6^{d}	8.9^{cd}	9.1^{cd}	8.3^{d}	10.7^{b}	6.4^{e}
Echinochloa colona	A	4.3^{e}	6.7^{d}	3.9^{e}	8.4^{c}	3.6^{e}	7.8^{cd}	8.4^{c}	29.1^{a}	16.3^{b}
	B	1^{c}	2^{c}	1^{c}	2^{c}	1^{c}	2^{c}	2^{c}	7^{a}	4^{b}
	C	10.9^{c}	16.2^{a}	8.7^{e}	10.5^{cd}	8.9^{f}	9.9^{d}	4.7^{f}	15.3^{b}	8.4^{e}
Fimbristylis miliacea	A	4.9^{f}	6.7^{ef}	6.0^{ef}	7.5^{e}	11.1^{d}	6.3^{ef}	15.5^{c}	24.8^{a}	21.1^{b}
	B	3^{f}	4^{ef}	3^{f}	5^{e}	7^{d}	4^{ef}	14^{c}	19^{a}	16^{b}
	C	12.4^{d}	16.2^{a}	13.4^{c}	9.4^{f}	15^{b}	8.0^{g}	8.6^{g}	13.0^{cd}	10.9^{e}
Other broad leaf	B	3^{de}	3^{de}	2^{e}	4^{cd}	3^{de}	2^{e}	6^{b}	5^{bc}	8^{a}
Total weed density (plants·m^{-2})		25^{d}	24^{d}	27^{d}	46^{c}	42^{c}	43^{c}	95^{b}	96^{b}	110^{a}
Total dry weight (g·m^{-2})		39.5^{i}	41.3^{h}	44.9^{g}	80.0^{d}	73.9^{f}	78.4^{e}	179.2^{c}	190.3^{b}	194.4^{a}
WCE (%)		73.7^{b}	75.0^{b}	75.4^{b}	51.6^{e}	56.3^{d}	60.9^{c}	0.0^{a}	0.0^{a}	0.0^{a}

Note: In the column, averages followed by the common letter(s) are not significantly different at level of P≤5% according to Duncan's Multiple Range Test.
A = Weed dry weight of given species (g/m^2); B = Weeds (No./m^2); C = Relative dry weight (RDW) %; WCE = Weed control efficiency (%).

Table 5 Weed species, weed density (No./m^2), weed dry weight (g/m^2), relative dry weight (RDW) % and weed control efficiency (WCE) % in the field 90 DAT

Weed species		Treatments								
		Mulching			Hand weeding			Weedy check		
		SF	HD-LF	HD-HF	SF	HD-LF	HD-HF	SF	HD-LF	HD-HF
Cyperus rotundus	A	20.4^{f}	10.8^{g}	24.5^{e}	27.1^{d}	10.6^{g}	37.2^{c}	57.2^{b}	55.4^{b}	68.6^{a}
	B	2^{c}	1^{c}	4^{bc}	2^{c}	1^{c}	4^{bc}	9^{ab}	11^{a}	14^{a}
	C	12.5^{b}	6.7^{g}	14.6^{c}	14.1^{bc}	4.7^{d}	16.1^{b}	22.9^{b}	20.6^{c}	24.0^{a}
Cyperus iris	A	17.8^{f}	20.6^{ef}	9.4^{g}	30.7^{d}	39.4^{c}	22.5^{e}	60.9^{b}	58.6^{b}	65.8^{a}
	B	2^{c}	2^{c}	1^{c}	2^{c}	3^{c}	2^{c}	11^{b}	12^{b}	16^{a}
	C	10.9^{c}	12.7^{c}	5.6^{g}	15.9^{b}	17.4^{b}	9.7^{cd}	24.4^{a}	21.8^{b}	23.0^{a}
Cyperus difformis	A	36.9^{ab}	43.0^{a}	34.7^{ab}	38.3^{ab}	33.0^{b}	42.4^{ab}	20.3^{c}	18.1^{c}	23.4^{c}
	B	13^{de}	15^{d}	14^{d}	11^{ef}	9^{f}	13^{de}	45^{b}	41^{c}	48^{a}
	C	22.6^{a}	26.6^{a}	20.7^{b}	19.9^{b}	14.6^{c}	18.3^{b}	8.1^{e}	6.7^{f}	8.0^{c}
Alternanthera sessilis	A	5.7^{d}	12.9^{a}	13.3^{a}	3.9^{e}	5.9^{d}	2.1^{f}	7.5^{c}	9.8^{b}	9.1^{b}
	B	2^{bc}	4^{ab}	4^{ab}	2^{bc}	3^{bc}	1^{c}	4^{ab}	6^{a}	6^{a}
	C	3.5^{f}	8.0^{e}	7.9^{f}	2.0^{e}	2.6^{e}	0.9^{e}	3.0^{f}	3.7^{g}	3.2^{d}

Weed species		Treatments								
		Mulching			Hand weeding			Weedy check		
		SF	HD-LF	HD-HF	SF	HD-LF	HD-HF	SF	HD-LF	HD-HF
Polygonum Lapathifolium	A	14.2^{c}	17.8^{a}	15.8^{b}	6.3^{e}	12.6^{d}	11.9^{d}	4.2^{f}	6.4^{e}	5.7^{e}
	B	2^{c}	3^{c}	3^{c}	2^{c}	3^{c}	2^{c}	3^{c}	8^{a}	5^{b}
	C	8.7^{d}	11.0^{d}	9.4^{e}	3.3^{e}	5.6^{d}	5.1^{de}	1.7^{f}	2.4^{h}	2.0^{d}
Monochoria vaginalis	A	13.1^{d}	12.5^{d}	18.9^{c}	11.7^{d}	8.9^{d}	9.1^{d}	27.1^{b}	22.6^{bc}	32.9^{a}
	B	6de	5^{ef}	8^{d}	4^{ef}	3^{f}	3^{f}	20^{b}	17^{c}	23^{a}
	C	8.0^{e}	7.7^{ef}	11.3^{d}	6.1d^{e}	3.8^{de}	3.9^{de}	10.8^{d}	8.4^{e}	11.5^{c}
Echinochloa colona	A	17.3^{d}	11.7^{e}	10.5^{e}	18.4^{d}	35.5^{c}	42.7^{b}	42.6^{b}	60.8^{a}	39.2^{bc}
	B	3^{a}	2^{a}	2^{a}	3^{a}	2^{a}	3^{a}	2^{a}	3^{a}	2^{a}
	C	10.6^{c}	7.2^{fg}	6.3^{g}	9.6^{cd}	15.7^{bc}	14.5^{bc}	17.0^{c}	22.7^{a}	13.7^{b}
Fimbristylis miliacea	A	37.6^{de}	32.4^{f}	40.2^{de}	56.2^{c}	79.9^{a}	63.4^{b}	30.3^{f}	36.6^{e}	41.1^{d}
	B	8de	6^{e}	8de	10^{cd}	14^{b}	12^{bc}	13^{b}	19^{a}	21^{a}
	C	23.1^{a}	20.0^{b}	24.0^{a}	29.2^{a}	35.4^{a}	27.4^{a}	12.1^{d}	13.6^{d}	14.4^{b}
Other broad leaf	B	7^{a}	5^{b}	4^{bc}	5^{b}	2^{c}	4^{bc}	4^{bc}	5^{b}	4^{bc}
Total weed density (plants·m^{-2})		45^{b}	43^{b}	48^{b}	41^{b}	40^{b}	44^{b}	111^{a}	122^{a}	139^{a}
Total dry weight (g·m^{-2})		163f	161.7^{f}	167.3^{f}	192.6^{e}	225.8^{d}	231.3^{d}	250.1^{c}	268.3^{b}	285.8^{a}
WCE (%)		59.5b	64.8^{b}	65.5^{b}	66.7^{b}	67.2^{b}	68.3^{b}	0.0^{a}	0.0^{a}	0.0^{a}

Note: In the column, averages followed by the common letter(s) are not significantly different at level of P≤5% according to Duncan's Multiple Range Test.
A = Weed dry weight of given species (g/m^{2}); B = Weeds (No./m^{2}); C = Relative dry weight (RDW) %; WCE = Weed control efficiency (%).

The plant height: The heights of plant were affected by crop weed composition and different water treatments. The maximum and minimum plant heights were 100.72 and 97.33 cm in hand weeding at HD-LF and SF treatments, respectively. Moreover, SF, HD-LF, and HD-HF were statistically significant. In addition, weedy plots showed 10.9% reduction in plant height. Similarly the maximum and minimum plant heights in mulching plots were 96.24 and 92.11 cm at HD-LF and SF treatments, respectively. These showed a reduction of 8.5% compared to hand weed control. However, HD-LF and HD-HF treatment in mulching were not significant. Tiller production also was influenced by water regimes. The maximum and minimum effective tillers per hill in hand weeding were 12.06 and 10.44 number of tillers per hill at HD-LF and HD-HF water treatments, respectively. There were no significant differences in HD-LF and HD-HF water regimes. In addition, mulching showed a maximum and minimum of 9.33 and 7.67 number of tillers per hill at HD-LF and SF water treatment, respectively. This showed a reduction of 36.4% compared to hand weeding (Table 6). The minimum number of effective tiller per hill was observed in weedy check plots showing reductions of 65.4% and 55.3% compared to hand weeding and mulching, respectively.

Filled Grain and Unfilled Grains per panicle: Mulching, hand weeding, weedy check and water treatment exerted significant influence on the filled grains and unfilled grains per panicle (Table VI). Mulching treatment produced maximum and minimum numbers of filled grains per panicle which were 201.94 and 191.49 at SF and HD-HF water treatment, respectively. In hand weeding, the maximum and minimum were 208.67 and 196.2 filled grain per panicle at HD-HF and SF water treatment, respectively. Moreover, water treatments were not significant in mulching and hand weeded treatments (Table 6). In addition, weedy check at HD-HF water treatment produced the minimum 142.22 filled grain per panicle showing a reduction of 29.6% and 31.4% in both mulching and hand weeding, respectively. On the contrary, the weed check at HD-HF water treatment produced the maximum number of unfilled grains per panicle 67.57 whereas hand weeding produced a maximum of 58 grain panicle^{-1} at SF water treatment. On the other hand mulching treatment at HD-LF water treatment produced a minimum number of unfilled grain per panicle 28.31 compared to mulching, showing a reduction of 58.1% and 51.2% for weedy check and hand weeding, respectively.

The weight of 1000-grains was significantly influenced by the treatments (Table 6). The highest weight of 1000-grains (28.33 g) was obtained from the mulching treatment at HD-LF water treatment and in hand weeding, the highest was (27.09 g) at HD-LF water treatment. The lowest weight of 1000-grains (25.66 g) was obtained from weedy check treatment at SF water treatment. Weedy check showed a reduction of 5.3% and 9.4% compared to hand weeding and mulching, respectively.

Table 6 Yield and plant parameters under three treatments with nine irrigation managements

Characters	Treatments								
	Mulching			Hand weeding			Weedy check		
	SF	HD-LF	HD-HF	SF	HD-LF	HD-HF	SF	HD-LF	HD-HF
Plant height (cm)	92.11±0.147^{e}	96.24±0.6^{d}	95.89±0.47^{d}	97.33±0.15^{c}	100.72±0.15^{a}	99.21±0.39^{b}	89.72±0.15^{g}	90.50±0.1^{ef}	90.33±0.74^{fg}
Effective tiller per hill	7.67±0.1^{d}	9.33±0.1^{b}	8.28±0.15^{d}	10.44±0.40^{b}	12.06±0.15^{a}	11.67±0.60^{a}	4.33±0.1^{e}	4.17±0.1^{e}	4.61±0.15^{e}
Filled grain per panicle (g)	201.94±2.38^{a}	199.75±13.76^{a}	191.49±18.34^{a}	200.00±0.98^{a}	208.67±1.80^{a}	196.2±1.96^{a}	144.18±6.43^{b}	145.39±5.36^{b}	142.22±3.38^{b}
Unfilled grain per panicle (g)	30.81±0.21^{cd}	28.31±5.78^{d}	33.17±3.49^{cd}	58.00±22.9^{b}	34.33±0.88^{c}	30.00±2.51^{cd}	61.93±2.11^{b}	60.33±5.24^{b}	67.57±2.43^{a}
Number of panicle/m^2	173.67±3.18^{b}	204.67±13.38^{ab}	189.67±4.06^{ab}	207.67±15.60^{ab}	223.33±1.45^{a}	200±30.09^{ab}	127.67±1.45^{c}	106.67±1.76^{c}	135.00±5.57^{c}
Weight of 1 000 grain (g)	26.15±0.28^{bd}	28.33±0.18^{a}	26.90±0.32^{bc}	26.67±0.48^{bc}	27.09±0.16^{b}	26.89±0.05^{bc}	25.69±0.16^{d}	25.89±0.06^{d}	25.66±0.05^{d}
Number of grains per panicle	209.94±16.19^{ab}	210.78±21.05^{a}	194.56±13.34^{b}	207.94±18.76^{ab}	196.89±15.37^{ab}	209.72±16.6^{ab}	60.33±21.3^{cd}	63.67±4.84^{cd}	46.67±3.84^{d}
Grain yield (kg/ha)	4033.4±141.38^{f}	5043.7±227.50^{b}	4342.4±47.16^{e}	4786.1 ±557.14^{c}	5157.5±73.36^{a}	4676.2±672.51^{d}	1166.8±81.45^{h}	1273.6±67.94^{g}	903±227.54^{i}
Straw yield (kg/ha)	5531.9±39.97^{e}	6722.2±76.72^{c}	6249.5±0.57^{d}	6067.4±5.71^{d}	7738.9±0.02^{a}	6940.1±0.23^{b}	2223.4±0.00^{f}	1384.9±1.14^{h}	1819.0±0.98^{g}
Biological yield (kg/ha)	9565.3±40.20^{d}	11766±75.59^{b}	10592±0.77^{c}	10854±4.96^{c}	12896±1.24^{a}	11616±2.75^{b}	3390.2±2.34^{e}	2658.5±2.73^{e}	2722±1.41^{e}
Weed index (%)	16.7±0.61c	5.7±0.23^{e}	8.5±0.59^{d}	0.0^{f}	0.0^{f}	0.0^{f}	75.0±0.45^{b}	75.5±0.58^{b}	80.9±0.81^{a}
Harvest index (%)	42.17±0.17^{bc}	42.87±0.29^{bc}	41.00±0.01^{bc}	44.10±0.03^{b}	40.00±0.01^{c}	40.19±1.42^{c}	34.42±0.03^{d}	47.91±0.03^{a}	33.17±0.05^{d}

Note: With each column for each cultivar, means followed by different letter are significantly different at P=0.05 level according to Duncan's Multiple Range Test.

Grain yield: Water regime practices, weeding and mulching caused significant variations in terms of grain yield irrespective of weed control treatments (Table 4). HD-LF water treatment contributed to superior performance over SF water treatment in terms of grain yield. Among the treatments, the highest grain yield was recorded from HD-LF water treatment and hand weeding (5 157.5 kg/ha). This may be attributed to the highest number of effective tillers per m^2, filled grains per panicle, heavier grains as well as lower number of unfilled grains per panicle. Apart from the hand weeding, the highest grain yield (5 043.7 kg/ha) was obtained when the plot was treated with mulching under HD-LF water treatment. Similar trends in yield components were also observed in this treatment. Yield was greatly affected by the weeds. The same treatment under weedy check water regime practice also produced the highest grain yield (1 273.6 kg/ha), showing a reduction, 75% lower than HD-HF water treatment in mulching and hand weeding. The lowest grain yield (903 kg/ha) was recorded in unweeded treatment at HD-HF water treatment. At HD-HF, water treatment in the uncontrolled weeds reduced the grain yield by 82%. It was found that in this treatment the lowest number of grain per panicle, weight of 1 000 grain was in filled grain panicle^{-1} whereas the highest was in unfilled grain per panicle. This might have been due to higher crop weed competition which limited resources during the treatment. Among the other treatments, SF at hand weeding produced 4 786.1 kg/ha followed by mulching at HD-HF water treatment which produced 4 342.4 kg/ha. Considering the results of the study, it might be reasonably argued that HD-LF water treatment with mulching might be considered as a viable option for better performance in terms of weed control efficiency (Table 6). This suggests that mulching with rice straw reduced the water loss and improved the grain yield of rice significantly.

The weed indexes for the weedy plots were 75%, 75.5% and 80.9% in the SF, HD-LF and HD-HF water treatments, respectively (Table 6). For the hand weeding plots, the weed index was zero because was used as a reference. On the other hand, the weed indexes in mulching plots were 16.7%, 5.7% and 8.7% in the SF, HD-LF and HD-HF water treatments, respectively. In mulching plots at HD-LF, the lowest weed index; 5.7% was found which was very close to that at HD-HF water treatment; 8.7%.

Grain yield was comparable when rice was grown under HD-LF and HD-HF conditions (Table 6). Results suggest that it is not necessary to flood rice to obtain high grain yield as maintaining a high dry low flooding soil throughout the growing season resulted in a significant reduction in rice yield. Grain yield, however decreased significantly when the field was under high dry low flooding condition, this is in agreement with previous findings[24, 25]. The low grain yield for rice subjected to weedy check condition was attributed to few panicles and less spikelets per panicle. Water treatment did not only affect grain but also straw yield (Table 6). The amount of straw produced under field capacity was about a half of the amount produced under flooded and saturated conditions. Shorter plants and fewer tillers might be attributed to the lower straw yield under field capacity conditions.

Straw yield: The mean maximum and minimum straw yields were 7 738.9 and 6 067.4 kg/ha at HD-LF and HD-HF water treatment, respectively. It showed a reduction of 21.6%. On the other hand, mulching treatments were 6 722.2 and 5 531.9 kg/ha at HD-LF and SF water treatments, respectively. It showed a reduction of 17.7%. Those in weedy check were 1 819 and 1 384.9 kg/ha at HD-HF and HD-LF water treatments, respectively. It showed a reduction of 23.9% (Table 6). Comparing to weedy check, hand weeding and mulching showed the reduction of 82.1% and 79.4% of straw yield, respectively. On the other hand, comparison between mulching and hand weeding showed a reduction of 28.5%. This indicates that straw mulch has a significant influence on grain yield. This is because straw mulch can increase soil water storage, decrease soil evaporation, and increase plant transpiration[26]. It can also regulate the available water to suit the water demand of the crop and satisfy the key water demand period[27]. The result was consistent with several previous studies which reported significantly increasing crop yields through mulching[26-30].

Table 7 shows the irrigation water delivery in the field during the rice growing period. According to the treatments applied, the lowest irrigation water delivery in mulching the field was 244.86 mm at HD-HF water treatment which had high control in rainfall water storage, followed by 300.1 mm at HD-LF water treatment whiles SF water treatment got highest irrigation water delivery in the field, 380.14 mm according to the controllable irrigation regime schedule. However, the weedy check showed the lowest, which was 389.16 mm at HD-HF water treatment, followed by 477.25 mm at HD-LF water treatment. Here too SF water treatment showed the highest irrigation water at 606.67 mm. In addition, hand weeding showed the highest amount of irrigation as well as higher number of irrigation schedule times in all water regimes and this was statistically significant. The seedling stage received less water than the other phases of development in both mulching and weedy plots because of the short period of this phase. The irrigation schedule in weedy plot showed 15 times water input for the conventional irrigation method SF water treatment while RCCI treatments showed 11 and 10 times HD-LF and HD-HF water treatments, respectively. However, mulching showed 13 times water input for the conventional irrigation method SF water treatment while RCCI treatments showed 10 and 8 times HD-LF and HD-HF water treatments, respectively. This shows a reduction of working time by the RCCI model in both mulching and weedy.

The Irrigation Water Use Indices (IWUI) and Crop Water Use Indices (CWUI) were the two key indices to evaluate the relation between water use and crop production. IWUI and WUI were calculated by grain yields of rice dividing by actual irrigation water input or total water input (including irrigation water and rainfall), respectively. The result (Table 8) indicated that with lower CWUI, there were higher yields compared to the corresponding higher CWUI. This was significant in the hand weeding plot where at the HD-LF water treatment the CWUI of 5.15 kg/mm produced 5 157.5 kg/ha while at the HD-HF water treatment the CWUI of 4.75 kg/mm produced 4 676.2 kg/ha. This is similar to those recorded under mulching and weedy check where the highest CWUI produced the highest yield and the lowest CWUI produced the lowest yield and were significant.

The above situation differs under the Irrigation Water Use Indices (IWUI), where under hand weeding and mulching, the minimum IWUI produced the maximum yield at HD-LF water treatment and the maximum IWUI produced the lowest yields at the HD-HF water treatment, respectively (Table 8). However, under mulching, weedy check and hand weeding results were significant in the SF water treatment. In weedy check, lower IWUI produced the lowest yields at the HD-HF water treatment and the highest IWUI produced the highest yields at the HD-LF water treatment. In mulching treatment, all water treatments showed a greater CWUI and IWUI compared to hand weeding and weedy check treatments. The above situation shows that the yield responds differently in CWUI and IWUI under mulching, hand weeding and weedy check. This indicates that straw mulch significantly influences IWUI and CWUI, which is in agreement with the results of several previous studies[26, 27, 30].

Table 7 Amount of water irrigated at different stages in the paddy fields (unit: mm)

Treatments		Seedling	Tillering	Elongation	Heading	Milk stage	Irrigation amount	Irrigation Schedule time
Mulching	SF	57.7^f	71.66^e	73.52^g	73.85^a	103.41^f	380.14^g	13^b
	HD-LF	47.82^g	60.22^f	56.65^h	59.69^b	75.37^h	300.1^h	10^c
	HD-HF	44.2^h	45.42^g	48.41^i	47.73^c	59.1^i	244.86^i	8^d
Hand weeding	SF	89.35^a	116.24^a	129.66^a	127.02^a	190.39^a	652.66^b	15^a
	HD-LF	72.24^c	92.64^c	101.29^c	105.91^a	134.86^c	680.12^a	11^c
	HD-HF	68.41^d	75.81^d	87.84^e	86.61^a	110.55^e	429.22^e	10^c
Weedy check	SF	82.43^b	110.24^b	122.54^b	119.11^a	172.35^b	606.67^c	15^a
	HD-LF	68.31^d	92.64^c	94.42^d	96.27^a	125.61^d	477.25^d	11^c
	HD-HF	63.14^e	69.87^e	80.68^f	76.98^a	98.49^g	389.16^f	10^c

Note: With each column for each cultivar, means followed by different letter are significantly different at P= 0.05 level according to Duncan's Multiple Range Test

Table 8 Crop water use indices

Treatment		Yield/kg · ha^{-1}	Irrigation/m^3	Evapotraspiration/mm	Crop WUI/kg · mm^{-1}	Irrigation WUI/kg · m^{-3}
Mulching	SF	4033.4^f	3801.4^f	706.8^f	5.71^c	1.061^c
	HD-LF	5043.7.4^b	3001^g	689.4^{fg}	7.41^a	1.680^b
	HD-HF	4342.4^e	2448.6^h	680.9^g	6.38^b	1.773^a
Hand weeding	SF	4786.1^c	6526.6^b	1242.4^a	3.85^e	0.733^d
	HD-LF	5157.5^a	6801.2^a	1001.1^c	5.15^d	0.758^d
	HD-HF	4676.2^d	4292.2^e	984.3^c	4.75^d	1.089^c
Weedy check	SF	1166.8^h	6066.7^c	1167.8^b	0.97^f	0.198^f
	HD-LF	1273.6^g	4772.3^d	946.3^d	1.30^f	0.272^e
	HD-HF	903^i	3891.6^f	918.6^e	0.91^f	0.226^f

Note: With each column for each cultivar, means followed by different letter are significantly different at *P*= 0.05 level according to Duncan's Multiple Range Test.

The Rain Catching and Controllable Irrigation (RCCI) model used efficient water inputs, rain and irrigation for grain production and was significantly different ($P\leq5\%$) from the conventional irrigation. HD-LF water treatment in crop production was the highest and had higher water use efficiency.

4 Conclusions

The highest weed population and dry weight of weeds were observed in weedy plots of both water treatments. Similar results were observed by several previous studies[31-33]. The yield loss due to weed competition was found to be 82.1% in the weedy plots under the water treatments. Similar results were observed by Smith[2]. In this investigation, effective tiller per hill, the number of panicles, the number of grains per panicle, the biological yield and the grain yield were higher in hand weeding and mulching plots than in weedy plots. And also, the number of panicle, unfilled grain, weight of1 000 grains, and harvest index were better in mulching plots than those in weedy plots. In mulching plots, due to the presence of straws, the rate of water evaporation was reduced and moisture in the soil was conserved although, hand weeding showed better results in plant height, filled grain, grain yield, biological, number of panicle per m and number of gain per panicle. Compared to the number of weeds and the amount of water used, the mulching treatment was better. Mulching also reduced the amount of weed emergence and there was a reduction in the amount of water at about 64% and 59.6 % in comparison to hand weeding and weedy plots, respectively. On the other hand, in the weedy plots rice plants were affected by weeds and water stress due to the presence of weeds that consumed more water and nutrients than the rice plants, hence the rice parameters were not good in these plots compared to those in the mulching and hand weeding treatment in all the water regimes.

From this investigation, it can be concluded that mulching under RCCI was an effective method to control weeds and reduce labor cost. In addition, mulching could decrease the use of herbicides and the risk of pollution. Furthermore, mulching could improve yield by controlling weeds and help save water.

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