Soil management systems improve water use efficiency of rainfed rice in the semi-arid tropics of Southern Lombok, Eastern Indonesia

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Abstract

Rice (*Oryza sativa*) grown on rainfed Vertisols in the semi-arid tropics of southern Lombok, Eastern Indonesia, is usually flooded in the short wet season, creating a considerable demand for water. However, rice crops and secondary crops frequently suffer from water stress as the soil dries after rainfall. Four systems of soil management for rice were studied at Wakan and Kawo, with average annual rainfalls of 984?mm and 1665 mm respectively. The objective was to improve water use efficiency (grain yield/m^3 water consumed). The four systems were unflooded permanent raised beds with tillage (RMT) or without tillage (RNT), and flooded flat land with tillage (FMT, the conventional system, *gogorancah*), or without tillage (FNT). Water was kept at 0.10?m depth in the furrows (RMT, RNT) or at 0.05 m depth above flat land (FMT, FNT). Excess water was collected in a dam (*embung*), and used when necessary to keep the water at the desired depth. Compared with FMT, RNT reduced crop water requirement for rice by 50% at Wakan and by 44% at Kawo. Water use efficiency in RNT was increased by 90% (Wakan), and by 56% (Kawo), compared with that in FMT. There were no differences between treatments in the yield of rice at Site 2 (4.5 t/ha), but at Site 1 yield was better in FMT or FNT (4.2 t/ha) than RMT or RNT (2.8 t/ha). Hence, on rainfed Vertisols of Southern Lombok, rice grown on permanent raised beds, with or without tillage, could successfully replace rice grown under the conventional flooded system with tillage on flat land (gogorancah), where the rainfall is higher. The extra water saved with permanent raised beds could be used to irrigate secondary crops.

Media summary

Water use efficiency of rice grown on unflooded permanent raised beds was higher than that of rice on flat land in vertisols of Eastern Indonesia.

Keywords

Water requirement, evaporation, paddy, precipitation.

Introduction

Drought is becoming more serious in many tropical countries due to an increase in climate variability. This results in poor rainfall distribution within the growing season, decreasing effective rainfall, and leading to long dry periods. Under these conditions, traditional systems of cropping and water management that use large volumes of water can further aggravate water shortages (Ibrahim et al. 1999). Borrell et al. (1998) suggested that better aligning crop growth with water supply could improve rice production in semi-arid regions. Water is the most limiting factor in rainfed rice production worldwide. Therefore, techniques that use less water and improve water use efficiency must be developed (Borrell and Van Cooten 2001).

Rice fields in the semi-arid tropics of southern Lombok, Eastern Indonesia, have frequently suffered from drought. Here, rice is commonly grown on flooded flat land resulting in a huge water demand. An alternative system of soil management involving growth of rice on permanent raised beds was intensively examined at two sites. The objective of the study was to improve water use efficiency of rice production by use of permanent raised beds. This system is appropriate in the region where local water storages called 'embungs' are available. Excess water from the permanent raised beds was temporarily collected in the embung.

Materials and methods

Location, climate and soil

Field experiments were conducted in the wet season of 2001/2002 at two sites in Southern Lombok, Indonesia, both at 8^{o} 45' S with Site 1 (Wakan) at 116^{o} 27' E, 100 m above sea level, and Site 2 (Kawo) at 116^{o} 20' E, and 180 m above sea level for Site 2 (Kawo). Average annual rainfall was 948 mm and 1665 mm, respectively. The sites have previously been cropped to rice under the traditional system of gogorancah (mixture of dry and flooded systems) since the 1980's. The soils are Vertisols (USDA 1998) with pH (1:5, soil:water) of?

6.6-8.2 (Site 1), and 6.5 –?7.7 (Site 2). The soil originated from parent material of alluvial clay dominated by montmorillonite.

Design and treatments

Field experiments were set up in the wet season of 2001/2002 in a randomized block design with three replicates at the two sites. We assessed the extent of interactions of crop x management x environment at the two sites (Wakan and Kawo). Four treatments of soil management were applied at each site. Plots, each 10 m long and 6?m wide, were separated by borders 0.2 m high and 0.5 m wide.

Rice was grown under four treatments of soil management: 1) permanent raised beds with no tillage (RNT), 2)?permanent raised beds with tillage (RMT), 3) flooded flat land with no tillage (FNT), and 4) flooded flat land with tillage (FMT, gogorancah). Treatments RMT and FMT were each tilled with a crow bar where the top 20?cm of soil was inverted and broken into clods 3 to 5 cm in diameter, similar to the traditional system of gogorancah. During the dry season (October 2001), permanent raised beds 1.2 m wide, 0.2 m high, 9.4?m long and separated by furrows 0.3 m wide, were constructed in treatments RNT and RMT. The tilled soils were sun-dried for one month before the wet season began. For treatments with no tillage, the herbicide Roundup™ (active ingredient of glyphosate at the rate of 30 mL/8 L water) was applied to control weeds.

Agronomy and irrigation

At the commencement of the wet season, the rice variety Widas was hand-sown after a cumulative rainfall of ≥?60 mm in 10 successive days. Five to six seeds were sown into holes (5 cm deep) with row spacing of 20?x?20?x 20?cm, giving a population of about 1100 Hills/plot in the permanent raised beds (RMT and RNT), and 1320?Hills/plot on flat land (FMT and FNT).

The water level in each plot was monitored daily. When the depth of water in the furrows (RNT, RMT) or on flat land (FMT, FNT) was half the desired depth, water was pumped from the embung to keep the water at 0.10 m depth (RNT, RMT) or 0.05 m depth (FMT, FNT). Excess water was discharged from each plot through outlets of bamboo set in the bund for each plot, measured, and pumped back into the embung. At 95 days after sowing (DAS), all plots were drained in preparation of harvest. Therefore, treatments on flat land were flooded for 35?days, i.e.?between 60 DAS to 95 DAS. The plots were not flooded for the first 60 days because there was no sufficient water available

Climate and water content in the soil

At each site, rainfall was recorded daily with a rain gauge (ombrometer), and evaporation was recorded daily with a Class A pan evaporimeter. Water content of the soil was measured weekly with a neutron probe (Campbell Pacific Hydroprobe Model 503) at 20 cm depth intervals from 20 cm to 1.2 m below the soil surface. Each week, the water content of soil from 0 to 20 cm depth was also determined gravimetrically.

Water lost through drainage, seepage and runoff was zero. Crop Water Requirement (CWR, mm), (water lost through evapotranspiration for the season), per treatment (total area: FMT, FNT 60 m^2; RNT, RMT 45 m^2) was calculated from: Change in water content in the soil (mm) + rainfall (mm) – evaporation (mm).

Water Use Efficiency (WUE, kg/m^3) per treatment was calculated from: grain yield (kg) / water used (m^3).

Harvest

Rice was harvested at 115 DAS when 90-95% of the florets in the panicle had yellowed. Hills (44/treatment) of rice plants were randomly sampled from the two middle beds (RNT, RMT) or from the middle of each treatment. Grain yield, straw biomass and 1000-seed mass (oven-dried 60^o C) were determined from each Hill and the mean per treatment calculated.

Results and discussion

In 2001/2002, the total rainfall at Site 1 was 34% lower than that at Site 2 (data not shown).

The crop water requirement at (Site 1) Wakan was higher than that at (Site 2) Kawo (Figure 1).

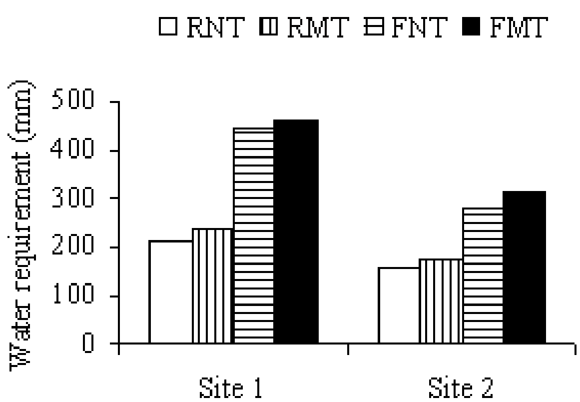

Figure 1. Crop water requirement (CWR) of rice on Vertisols under several systems of soil management at Site 1 (Wakan) and Site 2 (Kawo). [With (RMT), and without (RNT), tillage on permanent raised beds; with (FMT), and without (FNT), tillage on flat land].

(*p*-site = 0.003, LSD $_{0.05}$ = 41; (p-treatment = 0.002, $LSD_{0.05}$ = 53).

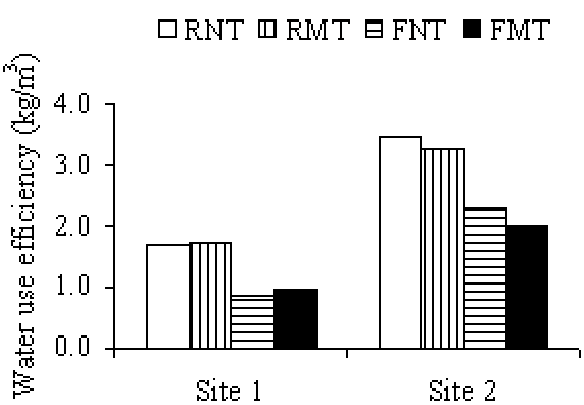

Figure 2. Water use efficiency (WUE) of rice on Vertisols under several systems of soil management (Figure 1) at Site 1 (Wakan) and Site 2 (Kawo).[With (RMT), and without (RNT), tillage on permanent raised beds; with (FMT), and without (FNT), tillage on flat land]. (*p*-site = 0.0001, LSD $_{0.05}$ = 0.4; *p*-treatment = 0.002, LSD $_{0.05}$ = 0.8).

Rice grown on permanent raised beds used half as much water as rice grown on flat land, with CWR reduced by 44% and 50% at Sites 1 and 2, respectively. Water requirements for flooded rice were significantly higher than for rice on permanent raised beds, supporting earlier studies in northern Australia. For example, Borrell et al. (1998) found that saturated soil culture (unflooded) on raised beds used 32% less water, with a higher water use efficiency, than did a flooded system on flat land. On flat land, the CWR of rice on treatments at the drier Site 1 (Wakan) was higher than the CWR at Site 2 (Kawo), with no significant differences between the treatments on flat land at each site (Figure 1). Hence evaporation is a major factor controlling crop water requirement (CWR). Total evaporation during the growth period of rice at Site 1 was 527 mm, and Site 2 was 563 mm. In a drier region, more water might be lost through evaporation from a free water surface in flooded soil, than that lost in a wetter region. Ibrahim et al. (1999) reported elsewhere that evaporation accounted for 20-40% of water lost from free water on the surface of tropical soil.

The WUE and yield of rice were each higher at Site 2 than that at the drier Site 1 (Figure 2, Figure 3). Compared with flat land (FNT, FMT), the permanent raised beds (RNT, RMT) increased WUE by 90% at Site 1, and by 56% at Site 2 (Figure 2). At the drier site (Site 1), the yield on flat flooded land was 49% higher than that on unflooded permanent raised beds (Figure 3). There was no significant difference in yield between treatments at Site 2. Hence, permanent raised beds appear to be well adapted at the wetter site (Site?2), but not at the drier site (Site 1) where the increase in WUE was at the cost of yield.

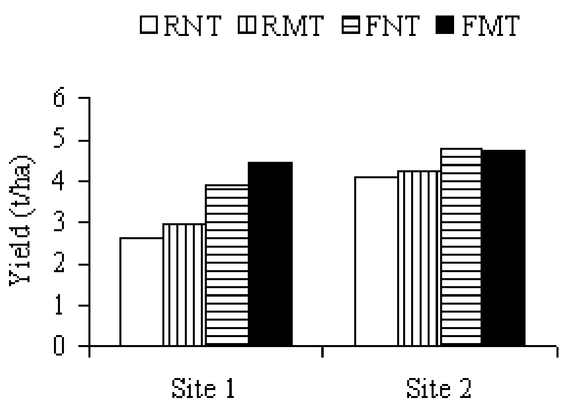

Figure 3. Yield of rice on Vertisols under several systems of soil management (Figure 1) at Site 1 (Wakan) and Site 2 (Kawo).
(*p*-site = 0.01, $LSD_{0.05}$ = 0.7; *p*-treatment = 0.02, $LSD_{0.05}$ = 0.8).

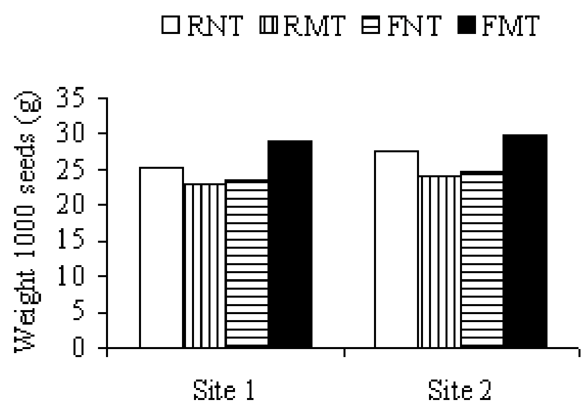

Figure 4. Weight of 1000 seeds of rice at Site 1 (Wakan) and Site 2 (Kawo) under different systems of soil management (Figure 1). (*p*-treatment = 0.0001, $LSD_{0.05}$ = 1.3).

Differences between treatments in weight of 1000 seeds were consistent across both sites (Figure 4), with FMT>RNT>FNT and RMT. Therefore, overall, it was not possible to attribute these differences to flat land compared with permanent raised beds, or to tillage compared with no tillage. One clear comparison, however, is that weight of 1000 seeds under tillage was higher on flat land rather than that on permanent raised beds.

Conclusion

With about 1660 mm (but not 950 mm) of rainfall on Vertisols of Southern Lombok, rice grown on permanent raised beds (1.2 m wide), with or without tillage, could successfully replace rice grown under the conventional flooded system with tillage on flat land (*gogorancah*). The extra water saved with the permanent raised beds could be used for irrigation of secondary crops.

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