GROWING MORE RICE WITH LESS WATER: ADAPTIVE WATER MANAGEMENT SCHEMES UTILIZED IN THE SYSTEM OF RICE INTENSIFICATION (SRI)

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ABSTRACT

Competition for limited water resources and low rice yields in developing countries has renewed the interest in finding better ways to grow more rice with less water. A promising strategy in Madagascar called System of Rice Intensification (SRI) has been found to increase grain yields while applying less water. SRI consists of a set of principles including aerating the soil during the vegetative development period and transplanting rice at a much earlier age (8-12 day-old) and at a lower density (25 hills per m^{-2} or fewer) than conventionally practiced. Two studies, one on-station and one on-farm, were undertaken to examine the water saving irrigation practices of SRI.

In the on-station study, two SRI water saving irrigation techniques (intermittent drying until the soil cracks and daily rotational irrigation) and continuous flooding at 5-cm depth were tested at two locations to determine effect on rice grain yield, irrigation water consumption, weed growth, and pest infestation. At both locations grain yield was not significantly affected by irrigation treatment. Compared with continuous flooding, on the organic soil at the first location, intermittent drying required 55% and daily rotational irrigation 9% less irrigation water. Intermittent drying used 19% less irrigation water compared with continuous flooding on the less permeable soil at the second location. The drawbacks with the water saving practices were a significantly increased susceptibility of young plants to attack by ground-burrowing insects and significantly more weed growth compared with continuous flooding.

For the on-farm study, 109 farmers were surveyed in four rice producing areas in Madagascar to investigate farmer implementation of SRI irrigation practices. The survey showed that farmers have adapted their water saving practices to fit the soil type and their availability of water and labor. The primary drawbacks reported by farmers with implementing the water saving alternate wet-dry (intermittent drying) and non-flooded irrigation practices were the lack of a reliable water source, little water control, and water use conflicts. SRI was associated with a significantly higher grain yield of 6.4 t ha^{-1} compared with 3.4 t ha^{-1} from conventional practices. On SRI plots, the grain yields were 6.7 t ha^{-1} for alternate wet-dry irrigation, 5.9 t ha^{-1} with non-flooded irrigation, and 5.9 t ha^{-1} for continuous flooding.

The results of the studies suggest that by combining SRI water saving irrigation with SRI cultivation practices, rice yields can be increased while significantly reducing irrigation water demand.

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CHAPTER 1

INTRODUCTION

Increasing global population and greater domestic and industrial demand for water have created the need to grow more food with less water. Rice is the staple food for nearly half the world's population and the most widely grown of all crops under irrigation (Guerra et al. 1998). Cultivated for thousands of years under inundated conditions, on average, rice requires twice the quantity of water per unit of production as any other cereal crop. Since major rice-producing countries like India, China, and Indonesia no longer enjoy an abundant water supply, experimentation has begun using less water in rice. Research on optimum soil moisture conditions for rice growth is far from conclusive. The results are highly variable across the rice domain. While little or no yield reductions have been observed under water-saving non-flooded conditions in some studies (Grigg et al. 2000, Singh et al. 1996, Mishra et al. 1990, Borrell et al. 1997), others showed dramatic decreases (De Datta et al. 1973, Wickham and Sen 1978).

A promising advance in growing more rice with less water has been made with the System of Rice Intensification (SRI) which was founded in Madagascar in the 1980's. SRI prescribes a set of practices, including early transplanting of seedlings (8-12 day old) at a low plant density (25 plants per m^{-2} or fewer) and application of organic matter or animal manure. In SRI, the soil is aerated during intermittent drying of the field throughout the vegetative growth phase. Only a little water (2-3 cm) is kept on the field during the reproductive and milk ripening stages. This set of cultivation and irrigation practices, collectively called SRI, has been widely reported to double and even quadruple the average (2.03 t ha^{-1}) rice yields in Madagascar (Vallois 1996, Uphoff 1999). For more detail on the SRI system, see Stoop et al. (2002).

The studies reported in this thesis examined the irrigation component of the System of Rice Intensification and assessed its potential to increase rice yields while reducing water consumption. In the first study, two SRI water saving practices (daily rotational and intermittent drying until soil cracks form) were tested in experimental field trials and compared with the conventional irrigation practice of continuous shallow submergence. The objectives of the study were to examine the effect of SRI water saving irrigation on rice grain yield, irrigation water demand, weed growth, and pest infestation. The second study surveyed 109 Malagasy farmers and measured their SRI and conventional rice grain yields. The objectives were to examine farmer adaptation, grain yields, and difficulties with water saving irrigation in Madagascar. Farmer implementation of these water saving practices is compared for the cases of SRI vs. conventional cultivation methods.

Before presenting the studies, a short review of literature on water management for lowland rice production is given in Chapter 2. This is intended to present current knowledge on optimum water management practices for rice production. A number of factors that in combination help determine the best irrigation practice for any given situation are discussed. Chapter 3 presents the on-station study which was conducted in Beforona, eastern Madagascar. Chapter 4 then presents the survey study which was conducted in the Antsirabe, Fianarantsoa, and Ambatondrazaka areas of Madagascar. In Chapter 5 a summary of the conclusions from the two studies and some recommendations for SRI water saving irrigation are given.

CHAPTER 2

LITERATURE REVIEW

Rice Ecosystems

Rice systems are classified as upland, rainfed and irrigated lowland, and flood-prone (deep-water) based on elevation, rainfall pattern, depth of flooding and drainage, and adaptation to these agroecological conditions (IRRI, 1999). Upland rice, which is cultivated under aerobic soil moisture conditions (similar to other cereal crops), produces yields of 1-3 t ha^{-1} and accounts for 4% of the world's rice production. Lowland rice, which includes rainfed and irrigated, is cultivated in flooded conditions up to 1 m depth. Lowland rice accounts for over 92% of the world's rice production and yields average 3-9 t ha^{-1} (IRRI, 1999). Flood-prone and deep-water rice is cultivated in areas where water control is limited and the flooding depth is greater than 1 m. Deep-water rice produces low yields and accounts for a small percent of global rice production.

Rice water management studies mostly focus on lowland systems because they produce the highest yields and allow for more water control than deep-water and upland rice systems. The current literature review will focus on lowland systems.

RICE PLANT WATER REQUIREMENTS DURING CROP DEVELOPMENT

Numerous studies show that rice plant water requirements change with each stage of crop growth. For water management purposes rice growth stages are usually divided as the seedling, vegetative growth (rooting and tillering), reproductive (panicle initiation, panicle differentiation, and anthesis), and ripening (grain filling and maturity) stages. Each growth stage responds differently to water management practices and will be discussed separately below.

Seedling

Water requirements of rice are low at the seedling stage. IRRI (International Rice Research Institute, 2000) recommends keeping the soil moist during germination or saturated (0 cm flood depth) for up 21 days after seeding. Evidence suggests that if seeds are submerged the development of radicles is affected by lack of oxygen supply (De Datta, 1987). Boonjung and Fukai (1996a) found that water stress during the seedling stage severely affects leaf and root development.

Vegetative Growth

There appears to be agreement in the international community that prolonged water stress and excessive water should be avoided during vegetative development. Prolonged water stress can reduce tillering, panicles per unit area, and spikelets per panicle (Boonjung and Fukai, 1996b). Excessive water hampers rooting and decreases tiller production (De Datta, 1987).

Various studies have given conflicting reports on optimum water management during vegetative growth. De Datta (1987) recommends continuous shallow submergence (2.5-7.5 cm depth) to facilitate tiller production and firm root anchorage. O'Toole and Moya (1981) suggest that water deficit during vegetative development may have little effect on grain yield. Several studies found that delaying flooding until just prior to or at panicle initiation had little or no effect on grain yield and significantly increased water-use efficiency (McCauley and Turner, 1979; Beyrouty et al., 1992; Norman et al., 1992; Lilley and Fukai, 1994; Grigg et al., 2000). Midseason soil drying during vegetative growth before panicle initiation, which is practiced in Japan and China, has been found to increase grain yields. This has been attributed to removal of anaerobic toxins, reduced ineffective late tillering, reduced lodging, increased N and P availability, and better root development (Wei and Song, 1989; Tuong, 1999; De Datta, 1987). Intermittent flooding in which the field is flooded and dried at regular intervals with periods of no standing water during vegetative development has been found to be as effective as, and sometimes even better than, continuous static flooding (De Datta, 1987; Devi et al, 1996; Prasad et al., 1997; Lourduraj and Bayan, 1999; Channabasappa et al., 1997; Raman and Desai, 1997; Sharma et al., 1997). Borrel et al. (1997) found that maintaining saturated (non-flooded) conditions in the paddy had no significant effect on yield quality or quantity as compared to the conventional practice of continuous shallow submergence.

Reproductive Stage

Rice plant water requirements are highest during reproductive development. Water stress during this period causes a reduction in number of filled spikelets which results in severe yield reductions (De Datta, 1987; Lilley and Fukai, 1994; Boonjung and Fukai, 1996b). Excessive water during reproductive development causes reduced culm strength and lodging which can result in significant yield reductions (De Datta, 1987; Setter et al., 1997; Sharma, 1999).

Most studies suggest that continuous saturation or shallow flooding (~5 cm) is the optimum water management for the reproductive stage. Studies have shown that less than saturated soil conditions during reproductive growth starting with panicle initiation can significantly reduce yields (De Datta et al 1973; IRRI, 1999). Borrell et al. (1997) found no significant yield difference between continuous saturated soil culture (SSC) and traditional flooding. Studies have shown that flooding depths greater than 5 cm during reproductive growth can reduce yields and greatly decrease water-use efficiency (De Datta and Williams, 1968; De Datta, 1987). Intermittent irrigation with periods of no standing water during reproductive growth has produced high yields in some studies (Devi et al, 1996; Prasad et al., 1997; Lourduraj and Bayan, 1999; Channabasappa et al., 1997; Raman and Desai, 1997; Sharma et al., 1997; Bin and Loeve, 2000) while in others significant yield reductions were reported (De Datta and Williams, 1968; De Datta, 1987).

Ripening Stage

Rice water requirements are low during the grain ripening stage. De Datta (1987) suggests that no standing water is required during most of the ripening stage. Flooded fields are usually drained at least a week before grain maturity (IRRI, 1999). Studies have found that terminating flooding as early as 2 weeks following heading does not effect grain yield or quality and can significantly reduce water consumption (Counce et al., 1990; Dingkuhn and Le Gal, 1996; Grigg et al., 2000).

OTHER FACTORS THAT AFFECT OPTIMUM WATER MANAGEMENT

Several factors in addition to the already discussed plant development water requirements must be considered in determining the best water management (i.e. producing the highest grain yield) for a particular lowland rice system. These factors which change with flooded and non-flooded conditions include soil physical and chemical characteristics, nutrient availability, weed and pest control, and climate. Optimum conditions will also vary for different rice varieties.

Soil Characteristics

Flooding modifies soil characteristics in ways that can be beneficial or harmful to rice growth. Table 2.1 lists some of the advantages and disadvantages of flooding. Beneficial effects of flooding include neutralization of acidic, calcerous, and sodic soils, alleviation of aluminum toxicity, and creation of soft tilth for easier root penetration. Harmful effects of flooding include buildup of toxic organic acids (acetic and butyric), toxic levels of ferrous iron, emission of gases (methane, hydrogen sulfide, carbon dioxide), and root hypoxia (Ponnamperuma, 1972, 1976; Sharma and De Datta, 1985). Non-flooded conditions can be beneficial to root growth due to increased soil aeration. Iron and organic acid toxicity can be effectively controlled with intermittent irrigation and mid-season soil drying (Tuong, 1999).

Nutrient Availability and Nutrient-Use Efficiency

Large amounts of nitrogen are lost from rice paddies upon flooding. These losses result from leaching and from the volatilization of ammonia and nitrogen gas produced by denitrification (Patrick et al. 1972). The leaching losses increase with depth of submergence due to increased percolation rates. Regions with Ustic moisture regimes (dry and rainy season) experience a nitrate flux at the beginning of the rainy season. This is due to increased mineralization of crop residues and conversion of ammonia to nitrate under aerobic conditions during the dry period (De Datta 1987).

Table 2.1 Continuous Flooding vs. Intermittent Flooding (Alternate Wet-Dry Irrigation)

	Continuous Flooding		**Intermittent Flooding**	
	Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Soil Properties	Increases pH of acidic soils and reduces pH of sodic and calcerous soils. Reduced Al toxicity. Softer tilth.	Buildup of toxic substances such as organic acids, ferrous iron. Emission of methane, CO_2 and hydrogen sulfide gas. Root zone hypoxia which can lead to inhibited root development and root rot.	Increased aeration of roots, oxidation of ferrous iron into non-toxic ferric iron. If well-timed can moderate soil temperature variation.	Water losses if soil cracks. Acidity, Al toxicity can be problems.
Nutrients	Increased availability of N, P, K, Si, Mb, Ca. N-fixation by algae and heterotrophic bacteria. Higher net mineralization of organic N.	Slower rate of mineralization of organic N, increased nutrient losses through denitrification and leaching. Decreased concentration of water-soluble Zn and Cu.	Faster N mineralization, increased N-fixation	High N losses due to denitrification and volatilization. Lower P, K, and Si availability in acid and nutrient poor soils during non-flooded period.
Weeds	Effectively controls grass and sedge weeds.	Increased broadleaf weed growth.	If flooding and drying period are well-timed can effectively control all types of weed growth.	Frequent weeding may be required to limit grass and sedge weed growth.

Upon re-submergence in preparation for the next rice crop most of this nitrate is lost (Macrae et al. 1968). This can result in a substantial decrease in overall nitrogen-use efficiency. Intermittent drying of flooded paddies results in the conversion of ammonium to nitrate which upon subsequent flooding is lost by denitrification (Sanchez 1973). A study on biological nitrogen fixation (BNF) found that alternate flooding and drying increased BNF rates substantially due to the use of built-up anaerobic products by aerobic nitrogen fixing organisms (Magdoff and Bouldin 1970). Kanungo et al. (1996) found that in soils with low percolation rates (2.3 mm day^{-1}) intermittent flooding supported better nitrogenase activity than continuous flooding.

Continuous flooding has been found to increase the availability of nitrogen, phosphorus, potassium, calcium, silicon, and iron. Flooding increases phosphorus availability by conversion of ferric P to ferrous P which is soluble and by increasing pH of acidic soils (Sanchez 1976). The greater percolation rates and presence of P in soluble form under submerged conditions can result in higher P and K leaching losses. Little research has been done on the effect of intermittent drying on P and K-use efficiency.

Weed and Pest Control

Flooding can be successfully used to minimize weed and pest infestation. Flooding greater than 16 cm depth eliminates grasses and almost completely controls sedges (De Datta et al, 1973). Broadleaf weeds can become a problem in some flooded systems. Shallow submergence (5 cm) limits most weed growth. Borrel et al. (1997) found similar weed populations under saturated and shallow flooded conditions. Weeds are more of a problem in non-saturated and non-flooded systems. Intermittent flooding can be effectively used to control weeds if the flooding and drying periods are timed well.

Climate

Flooding can be used in some colder climates and at high altitudes such as in Japan to moderate soil temperature. Low soil temperature has been found to lengthen the growing season and reduce rice yields. Flooding fields in the evening to insulate them during the cold nights and draining during the day to absorb heat is practiced in Japan.

CONVENTIONAL IRRIGATED LOWLAND RICE SYSTEMS

Conventional irrigated lowland rice is cultivated under continuous shallow flooding (~2-15 cm) from vegetative growth until the dough ripening stage. Most of the international community currently recommends this practice as the optimum water management for rice production. Continuous flooding is the most widely practiced method for irrigated rice production. The International Rice Research Institute (2000) recommends maintaining 2-5 cm submergence during tillering, 5 cm submergence during stem elongation and reproductive growth, and 1-3 cm during the milk and dough ripening stages. In experiments with different ponding depths (0,3,6,9,12,15, and 18) and intermittent irrigation (irrigation after disappearance of ponding water), Anbumozhi et al. (1998) found that 9 cm ponding depth gave the best growth and yield under all ponding conditions. De Datta and Williams (1968) obtained highest grain yields under 7.5 cm continuous flooding compared to intermediate irrigation, and 2 and 15 cm continuous flooding. De Datta (1987) suggests that continuous static flooding 2.5-7.5 cm has the potential to produce optimum rice yields. Bhuiyan (1998) found N application in continuous standing water and continuous standing water with drainage up to saturation is better (increased nutrient-use efficiency and uptake of applied N) than N application in less than saturated conditions.

WATER SAVING PRACTICES

Numerous studies have examined methods to reduce water consumption in rice production. These studies have shown that continuous submergence is not essential for high rice yields. Some of the water management practices that have been investigated for decreasing water consumption in rice are rotational irrigation (alternate-wet dry irrigation), mid-season drainage, delayed flooding, saturated soil culture, and IWMI's (International Water Management Institute) water saving irrigation (WSI).

Rotational Irrigation (Alternate Wet-Dry Irrigation)

Rotational or cyclic irrigation in which the field is irrigated at regular intervals with periods of no standing water has been found to be as effective as, and sometimes even better than, continuous static flooding (De Datta, 1987; Devi et al, 1996; Prasad et al., 1997). It also results in lower water use (Lourduraj and Bayan, 1999; Channabasappa et al., 1997; Raman and Desai, 1997; Sharma et al., 1997). The recommended practice of continuous submergence for two weeks followed by subsequent irrigation at 2-day drainage period (time after ponded water vanishes from the surface) in Punjab, India was found to produce optimum yields. This practice saved, on an average, 73% irrigation water compared with the traditional practice of continuous shallow submergence (Singh et al. 1996). In the Tarai region of India a study was done using 6 different water regimes and two different groundwater depths. The study concluded that optimum yield with high water-use efficiency is obtained by intermittent irrigation 3 to 5 days after the water vanished from the surface for shallow water tables (0.7-92.3

cm) and 1-3 days under medium water tables (12.6-126.3 cm), instead of their traditional practice of continuous submergence (Mishra et al. 1990). Khade et al. (1997) found that irrigation 2 days after subsidence of ponded water (DASPW) produced higher grain yield than irrigation 4, 6, and 8 DASPW. Uppal and Bali (1997) obtained higher yields with irrigation 2 DASPW and 15-20 days initial submergence than with irrigation 4 DASPW and 5, 10, and 15 days of initial submergence.

Mid-season Drainage

Mid-season drainage during the vegetative growth stage as is practiced in China and Japan has been found to increase yields and reduce water use (Brahmanand et al., 2000, Tuong, 1999). Greater yields have been attributed to removal of anaerobic toxins, reduced ineffective late tillering, reduced lodging, increased N and P availability, and better root development (Wei and Song, 1989; Tuong, 1999; De Datta, 1987). Tuong (1999) suggests if the midseason soil drying is done properly (not too long to prevent large cracks from forming which can lead to increased water loss) it can effectively save water.

Delayed Flooding

Delayed flooding in lowland rice systems reduced water consumption without sacrificing yield in several studies (McCauley and Turner, 1979; Beyrouty et al., 1992; Norman et al., 1992). Tanaka et al. (1964) suggested that yields should not differ between delayed flooded rice and rice flooded during the entire season as long as the non-flooded period does not stress the rice plant. Grigg et al. (2000) found that the duration of the flood before and after the reproductive period had no appreciable effects on grain yield or quality. Lilley and Fukai (1994) found that water deficit during vegetative development did not reduce yields while water stress during reproductive growth resulted in 20-70% less grain yield. Furlani et al. (1995) determined that delaying flooding until 74 days after emergence reduced grain yield and also prolonged the growth season compared to delaying flooding until 15 and 42 days after emergence. Water use was reduced by 30% without incurring significant yield loss in a study in Australia that delayed permanent flooding until two weeks before panicle initiation (Heenan and Thompson, 1984,1985).

Saturated Soil Culture

Saturated soil culture (SSC) for rice production has been reported to reduce water use by 25-50% without any significant yield loss (Subramanian et al., 1978; Jha et al., 1981; Tabbal et al., 1992). This method involves keeping the soil saturated with no standing water throughout the rice growing season. Borrel et al. (1997) found SSC used about 32% less water than traditional flooded production without any significant difference in grain yield or quality. Saturated conditions were maintained by growing the rice on raised beds and maintaining water in the furrows around the beds. Weed populations were similar for the SSC and traditional flooded production suggesting that weeds can be controlled with SSC.

Water Saving Irrigation

The International Water Management Institute is currently conducting experiments in China on "water saving irrigation" (WSI). The basic feature of this irrigation method is no standing water in the paddy fields during the growing season of rice after the last stage of tillering (see Table 2.2). This method has been found to both save water and increase yields (Bin and Loeve, 2000).

Table 2.2 Summary of Water Saving Practices

Growth Period	Continuous Shallow Flooding	Rotational	Delayed Flooding and Early Drainage	Saturated Soil Culture	Water Saving Irrigation (WSI)
Vegetative Growth	2~5cm	1-8 *DASPW~ 5cm	Moist	~0mm	80% ~ 30mm
Reproductive Stage	~5cm	1-8 DASPW~ 5cm	~5cm	~0mm	80% ~ 40mm
Milk Ripening Stage	1~3cm	1-8 DASPW~ 5cm	Moist	~0mm	70% ~ 20mm
Yellow Ripening Stage	Drained, Dry	Drained, Dry	Drained, Dry	Drained, Dry	Drained, Dry

* Days after subsidence of ponded water

CONCLUSIONS

Improved water management for rice production is needed to reduce pressure on scarce water resources and to feed an increasing world population. There are conflicting reports in the literature on optimum water management for rice production. Many studies recommend continuous shallow submergence. However, there has been an increasing number of studies that have found that other practices such as rotational irrigation (alternate wet-dry irrigation), mid-season drainage, delayed flooding, saturated soil culture, and water saving irrigation produce yields as high as, and sometimes even higher than, continuous flooding while reducing water use significantly. Results of studies of different water management practices vary however with soils, climate, and other agroecological conditions.

There appears to be agreement in the literature that reproductive growth is the most critical period during plant development when water requirements are highest. There are conflicting reports, however, on optimum water management during vegetative growth, reproductive development, and grain filling. Many studies have found no significant difference in yields under non-flooded, intermittently flooded, and saturated conditions during those periods, while numerous other studies obtained significant yield reductions. More research is needed to determine optimum rice water management for different agroecological conditions.

CHAPTER 3

WATER-USE EFFICIENCY OF ALTERNATE WET-DRY IRRIGATION IN THE SYSTEM OF RICE INTENSIFICATION

ABSTRACT

Competition for limited water resources and low rice yields in developing countries has renewed the interest in finding better ways to grow more rice with less water. This study tested two promising water saving irrigation techniques used in Madagascar to determine effect on rice grain yield, irrigation water consumption, weed growth, and pest infestation. Two methods of alternate wet-dry irrigation (AWDI – intermittent drying until the soil cracks and DR- daily rotational, both applied only during the vegetative period of crop development) were tested at two adjacent locations with different soil fertilities and organic matter contents and compared to the conventional practice of continuous flooding (CF). At both locations grain yield was not significantly affected by irrigation treatment. AWDI and DR used 55% and 9%, respectively, less irrigation water compared with CF on the organic soil. At the second location on the less permeable soil, AWDI used 19% less irrigation water compared with CF. The drawbacks with the AWDI and DR treatments were a significantly increased susceptibility of young plants to attack by ground-burrowing insects and significantly more weed growth compared with CF. The results of this study suggest that alternate wet-dry irrigation is an effective method to reduce irrigation water demand in lowland rice cultivation without significantly affecting grain yield.

INTRODUCTION

Increasing global population and greater domestic and industrial demand for water have created the need to grow more food with less water. Rice is the staple food for nearly half the world's population and the most widely grown of all crops under irrigation (Guerra et al. 1998). Cultivated for thousands of years under inundated conditions, on average, rice requires twice the quantity of water per unit of production as any other cereal crop. Since major rice-producing countries like China, India, and Indonesia no longer enjoy an abundant water supply, experimentation has begun using less water in rice (Guerra et al. 1998). Experiments described in this chapter, although conducted in eastern Madagascar, provide options for increasing productivity of water in irrigated rice cultivation throughout the tropics.

Traditionally rice is cultivated under continuously flooded conditions in Madagascar. However, there are currently several thousand farmers throughout the island who practice alternate wet-dry irrigation during the vegetative phase of crop development (Vallois 1996). Farmers have adopted these water saving irrigation practices as part of a new strategy of rice intensification, called SRI (System of Rice Intensification), which was developed in Madagascar in the 1980's. SRI recommends farmers combine these new water management practices with transplanting younger (8-12 day-old) seedlings at a lower plant density (25 hills per m^{-2} or fewer) and with fewer plants (one plant) per hill compared with conventional cultivation methods. The primary reason farmers apply SRI is to increase grain yields. Farmers have reported 50-200 % increase in yields without the use of chemical fertilizers (Uphoff 1999; Vallois 1996). For more detail on the SRI system, see Stoop et al. (2002).

Rice does not need to be permanently flooded to produce high yields (van der Hoek et al. 2001). Rotational irrigation with irrigation 1-5 days after subsidence of ponded water (DASPW) has produced the same or higher grain yield as continuous flooding (Devi et al, 1996; Prasad et al., 1997; Mishra et al. 1997) while at the same time reducing water loss (Lourduraj and Bayan, 1999; Channabasappa et al., 1997; Raman and Desai, 1997; Sharma et al., 1997; Singh et al. 1996). Similarly in USA and Australia delayed flooding reduced water consumption without significant reduction in yields (McCauley and Turner, 1979; Beyrouty et al., 1992; Norman et al., 1992; Grigg et al. 2000). Borrel et al. (1997) found that growing rice with saturated soil, under non-flooded conditions, used about 32% less water than traditional flooded production without any significant difference in grain yield or quality.

Water requirements in rice are highest during the reproductive stage and little opportunities exist to lower water use during this period (De Datta 1987). However, during other periods of rice development water consumption can be reduced. Grigg et al. (2000) found that the duration of the flood before and after the reproductive period had no appreciable effects on grain yield or quality. Lilley and Fukai (1994) showed that water deficit during vegetative development did not reduce yields while water stress during reproductive growth resulted in 20-70% less grain yield.

The objective of the current study was to test the Malagasy system of alternate wet-dry irrigation in which the paddy is periodically dried during vegetative growth and continuously flooded during the reproductive and milk ripening stages. The effects of irrigation practice on grain yield, field level water consumption and water-use efficiency, weed growth, and pest infestation are investigated.

MATERIAL AND METHODS

Site and Environmental Conditions

A field experiment was conducted during the rainy season from December 2000 to May 2001 at two locations (referred to as location 1 and location 2) within the CDIA (*Centre de Diffusion pour l'Intensification Agricole*) agricultural extension station in Beforona-Marolafa, eastern Madagascar (48°30'E , 18°50'S, 525 m above mean sea level). The soil at both locations was a deep acidic humic Ferasol with a sandy loam texture (15% clay, 24% silt, 61% sand) in the top 30 cm. The main difference between the two locations of the study was the soil nutrient and organic matter content. Soil nutrients and organic matter content for each plot (0-30 cm depth) were analyzed in the laboratory using composite soil samples consisting of 5 sub-samples per plot. As seen in Table 3.1, the soils at location 2 were poorer in N, K, C, organic matter, and CEC compared with those at location 1. Nitrogen is the limiting element for rice production on these soils (Barison 2002).

The plots at location 1 had been fallow with no nutrient additions from 1986-1998. Rice was cultivated on these plots with no nutrient additions during 1999. In August 2000 (4 months prior to this study) 4 t ha^{-1} compost made with bush vegetation and 6.2 t ha^{-1} swine manure were applied to cultivate potatoes. This is a common off-season crop for rice farmers in Madagascar.

Table 3.1 Soil Characteristics of Plots before Puddling

Site	**pH** 1:1 H_2O	**N** (%)	**P** (ppm)	**K** ($cmol_c$ kg^{-1})	**C** (%)	**C/N**	**Organic Matter** (%)	**CEC** ($cmol_c$ kg^{-1})
Location 1	4.72	0.15	7.81	1.49	2.15	14.4	3.70	13.5
Location 2	4.66	0.11	13.1	1.10	1.54	13.3	2.66	9.0
Difference (%)	**1.3** ^{ns}	**22.5** **	**40.4** ^{ns}	**26.2** *	**28.4** **	**7.4** ^{ns}	**28.1** **	**33.1** **

*Significant at $p = 0.10$; ** Significant at $p = 0.05$; ^{ns} Not significant at $p = 0.10$

a.) Total Kjeldahl Nitrogen

b.) Bray II-P

The plots at location 2 were fallow with no nutrient additions from 1996-1997. Rice with no nutrient additions was grown on these plots from 1997-1999. Beans, which is another common off-season crop in Madagascar, was cultivated with addition of 25 t ha^{-1} of compost (made with bush vegetation) in May 2000 (6 months prior to this study).

The soils of the terraced paddies at both locations were highly permeable (2.4~7.8 cm day^{-1}) compared with most puddled rice soils, the percolation rates also varied greatly between all the plots used for the study (discussed in the results). The average saturated hydraulic conductivity (K_{sat}) for the subsoil at both locations was about 100-115 cm day^{-1} as measured with three auger-hole tests at each location.

Experimental Design

A randomized complete block design was used with two replications at location 1 (more fertile soil) and three replications at location 2 (poor soil). The treatments for the study were: daily rotational (DR) irrigation, alternate wet-dry irrigation (AWDI), and continuous shallow flooding (CF). Location 1 tested all the treatments while location 2 only tested AWDI and CF. Each experimental plot occupied 21-25 m^2. Plots within each block were separated by 75-cm wide earthen bunds. Blocks were placed on separate but adjoining levels of the terraced paddies.

The irrigation practices tested in this study were based on principles of the Malagasy System of Rice Intensification (SRI). SRI water management principles require irrigation with “a minimum of water” in which the soil is oxygenated by periodic drying during the vegetative growth period to reportedly provide for better root growth, nutrient uptake, and tillering (Vallois 1996). Time and space allocation only permitted us to test the two extremes (most and least frequent irrigation) of the SRI wet-dry irrigation schemes consisting of daily rotational (DR) and intermittent drying until the soil cracks (AWDI). These were compared to the traditional practice of continuous flooding (CF).

Irrigation was similar for all treatments during the seedling, reproductive, and grain ripening stages of crop development. Table 3.2 shows the irrigation practices during each period of crop growth. Differences in the irrigation treatments occurred during the vegetative stage. For daily rotational (DR) irrigation, the plots were flooded to 3 cm depth every evening after which the irrigation inflow was stopped and the plots left to drain until the next morning with the exit gates closed. In the morning the water remaining in the paddy was let out and the exit gate left open during the daytime. This cycle was repeated everyday from transplanting until the panicle initiation stage of rice growth. For alternate wet-dry irrigation (AWDI) plots were flooded to 2 cm and then left to dry for 2-7 days until cracks of approximately 1-cm width formed.

After the cracks formed, if there was not enough rain (~5mm d^{-1}) to keep the soil visibly moist, the plots were flooded to 2 cm again and left to dry. This cycle with variable duration depending on rainfall and observed soil moisture was repeated until the panicle initiation stage of crop growth. For the continuously flooded (CF) treatment the plots were kept submerged at 3-5-cm depth. All treatments were kept continuously flooded at 2-5 cm depth starting at panicle initiation through the reproductive growth and milk ripening stages.

Table 3.2 Irrigation Treatments: Daily Rotational (DR), Alternate Wet-Dry Irrigation (AWDI), and Continuous Flooding (CF).

Growth Period	**Duration (days)**	**Daily Rotational (DR)**	**Alternate Wet-Dry Irrigation (AWDI)**	**Continuous Flooding (CF)**
Nursery	8	Moist	Moist	Moist
Vegetative	65	Flood ~3 cm at night, drained during day	Dry soil until 1-cm wide cracks form then flood ~2 cm. Repeat cycle. Do not irrigate if have over ~5mm-d^{-1} rain.	3~5 cm
Reproductive	31	2~3 cm	2~3 cm	3~5 cm
Milk Ripening	20	~3cm	~3 cm	~5 cm
Yellow Ripening	14	Drained Dry	Drained Dry	Drained Dry

Cultural Details

The cultural practices and timing of activities were the same for all plots at both locations. One week before transplanting 10 t ha^{-1} of compost (80 N, 0.2 P, and 87 K kg ha^{-1}) was applied to all plots just before puddling. No chemical fertilizers, herbicides, or soil amendments were used in this study. All plots were puddled to a depth of 20-30 cm. Pre-germinated seeds were sown in a moist raised-bed nursery. The nursery was kept moist by irrigation with a watering can and direct rainfall. The seed cultivar used was a local farmer-preferred medium-duration, medium height, medium-grained Indonesian indica variety, known locally as Soamalandy and nationally as Fofifa variety 2787. Eight-day old seedlings (two-leaf stage) were transplanted with one plant per hill in rows of 25 x 25 cm spacing (16 plants m^{-2}). For the first two weeks after transplanting, plants damaged by insects were replaced. All plots were weeded 3 times (10, 35, and 60 days after transplanting) during the vegetative growth phase using a hand-pushed rotary weeder.

Irrigation and Soil-Water Measurements

Cumulative irrigation application to each plot was determined by summing daily irrigation inflow. Irrigation inflow was calculated as flow rate at the point of entry into the plot times the duration of irrigation. Flow rate was determined by measuring the time to fill a 10-liter container. Flow rate measurements were taken once immediately before the start of, once during, and once immediately after irrigation. Water was conveyed to plots with split bamboos making flow measurements easier.

Internal drainage rates were measured for all plots with in-situ seepage and percolation (S&P) tests. Seepage and percolation rates were estimated as the change in water depth (at initial 2-5 cm ponding depth) minus total evapotranspiration (ET) over 6-hour test periods. S&P was measured once during the middle of the vegetative stage and five times (about once every two weeks) during the reproductive and grain filling stages of crop growth.

Gravimetric soil moisture content was measured at the end of several drying periods immediately before irrigation of AWDI and DR plots to estimate minimum soil moisture during vegetative growth. Core samples were taken separately from the 0-15 cm depth and 15-30 cm depth. Samples were immediately weighed in the field. The samples were weighed again following air-drying for several weeks. Samples were weighed a third time after oven drying for a 24-hour period at 105^{o}C.

Plant and Yield Measurements

Dry matter samples were taken at physiological maturity from four 0.25 m^2 quadrats on each plot. Samples were cut at ground level and oven dried before weighing. Grain yield was measured from 3x3 m^2 quadrats in the center of the plot. Paddy yields were converted to 14% moisture content based on measured grain humidity during weighing. Total tillers and fertile tillers were counted at maximum tillering and physiological maturity, respectively. The panicles per clump, total tillers per clump, and spikelets per panicle were counted on four randomly selected plants at each corner of the plots (~1 m^2 total area). The plants at the plot corners were more productive than the plants at the center of the plots where the yield was measured. For that reason the yield components will overestimate measured yields.

Weed and Pest Infestation

Weed number and fresh biomass were measured from 1-m^2 quadrats. Measurements were taken on the same day just before the weeding operation. Only weeds that were large enough to remove manually without digging the soil were included in the weed measurements. Pest damage to young plants during the first two weeks after transplanting was measured as number of plants out of the total number of plants on the plot that was missing or fatally damaged and that had to be replaced.

Statistical Analysis

Grain yield, irrigation application, plant production, weed infestation, and pest damage were analyzed using two-way analysis of variance in MINITAB (MINITAB Inc. 2000). Treatment comparisons were analyzed with Fisher's protected least significant difference method. This method was chosen because of its sensitivity in detecting differences between treatments and its ability to control the error rate for each pair-wise comparison. The protected method was used to control the overall error rate. Treatment comparisons were calculated separately for location 1 and location 2. Treatments were considered significantly different at the 5 % level.

RESULTS AND DISCUSSION

Meteorology

Total precipitation during the rice growth period from the end of December 2000 to April 2001 was about 1300 mm at the CDIA extension station (BEMA Marolafa Weather Station, 2001). More than half of this rainfall came during the month of January which received significantly more than its normal average rainfall (Table 3.3).

Mean air temperatures during the study averaged 23.8°C with mean maximum of 26.2°C and mean minimum of 21.4°C.

Phenology

The entire rice growth period was 138 days. Table 3.2 shows the average duration of each phase of crop development. Anthesis occurred about 104 days after seeding (DAS) for all irrigation treatments at both locations. Irrigation had an impact on crop phenology. For the daily rotational irrigation (DR) plots panicle initiation occurred 70 DAS compared with 73 DAS for alternate wet-dry irrigation (AWDI) and continuous flooding (CF). The duration of the DR reproductive period was 34 days compared with 31 days for the other irrigation treatments. All plots at both locations reached maturity at the same time. The AWDI and CF plots at both locations did not have any significant differences in phenology.

Table 3.3 Rainfall Amount and Distribution, Evapotranspiration, and Mean Air Temperatures during 2000-2001 (Source: BEMA Marolafa Weather Station, 2001)

Month	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Precipitation (mm) (10-year average)[a]	265 (131)	451 (285)	795 (396)	124 (505)	223 (533)	160 (201)	90 (123)
Rainfall Distribution (Days)	18	24	26	14	26	14	21
Evapotranspiration (mm)	63.7	57.8	41.6	57.7	55.6	54.4	50.8
Mean Temperature (°C)	22.0	24.8	25.0	24.7	24.4	23.2	21.5

a.) 10-year average monthly rainfall (1984-1994)

Cumulative Water Use

Method of irrigation considerably affected cumulative water use at both locations. Figure 3.1 shows the cumulative irrigation applied for each treatment. DR-1, AWDI-1, and CF-1 refer to the treatments at location 1 while AWDI-2 and CF-2 were the treatments at location 2. Mean daily water application during the season for the alternate wet-dry irrigation (AWDI-1, AWDI-2) at both locations was significantly less ($p = 0.05$) than for the daily rotational (DR-1) and continuously flooded irrigation (CF-1, CF-2). However, the difference in water use between DR-1 and CF-1 was not statistically significant. Total irrigation water applied as a percentage of CF-1 was 91% for DR-1 and 45% for AWDI-1. Irrigation water use on the less permeable soil at location 2 was 19% less for AWDI-2 compared with CF-2. The water savings of DR-1, AWDI-1, and AWDI-2 occurred during the vegetative growth period when irrigation was different between treatments (Figure 3.1).

The total irrigation applied at both locations was very high (1899 - 4044 mm) due to the high infiltration losses on the terraced paddies. Table 3.4 presents the results of the seepage and percolation (S&P) tests. Measured S&P rates for all plots were high ranging from 2.4 – 5.6 cm day^{-1} during the vegetative growth period and from 5.3 – 7.8 cm day^{-1} during the reproductive and grain fillings periods. Soil cracking and hardening could be a reason for the difference in S&P rates observed between treatments. AWDI and DR produced significant cracking during vegetative growth. Cycles of wetting and drying in the AWDI-1 and AWDI-2 plots also resulted in soil hardening and surface crust formation. On the second day of the on average 2-day wetting period of the AWDI-1 and AWDI-2 irrigation cycle when S&P tests were

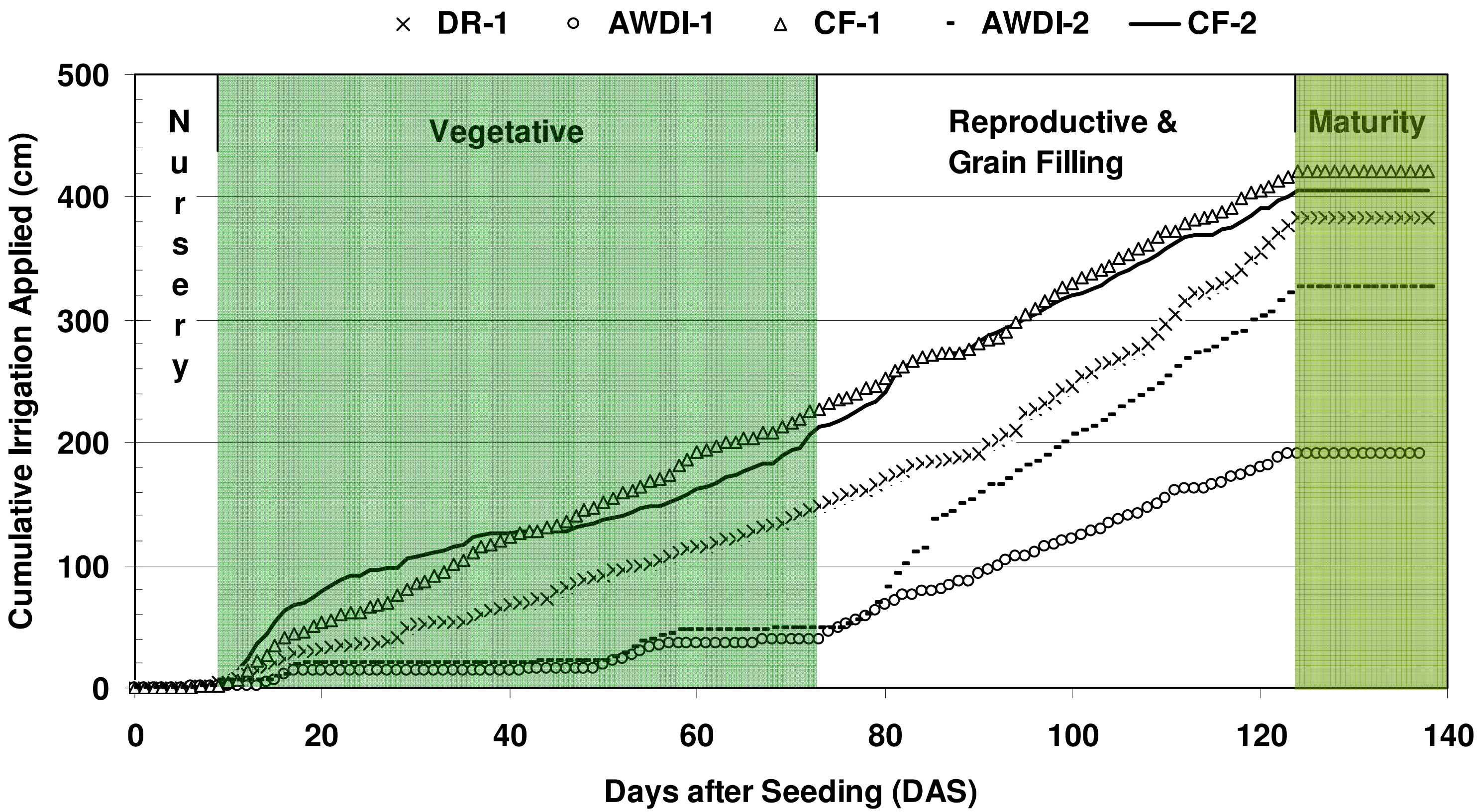


Figure 3.1 Cumulative Irrigation Applied at Both Locations

Table 3.4 Seepage and Percolation Rates in cm d^{-1} as a Function of Treatment and Growth Period

Period	Location 1			Location 2	
	DR-1	AWDI-1	CF-1	AWDI-2	CF-2
Vegetative Growth	2.4 (0.3)[a] ns	3.3 (1.2) ns	5.6 (1.4) ns	3.6 (1.1) ns	4.7 (2.9) Ns
Reproductive & Grain Filling	7.8 (3.6) ns	6.1 (1.8) ns	7.7 (7.3) ns	6.8 (1.0) ns	5.3 (1.0) Ns
Percent Change	+ 225 ns	+ 85 ns	+ 38 ns	+ 89 *	+ 13 *

a.) Standard deviations in parentheses

* Difference between treatments within location significant at p = 0.05

ns Difference between treatments within location not significant at p = 0.05

conducted the surface crust appeared to limit percolation rates and percolation through the cracks and crack walls was the dominate transport path. However, during the reproductive growth and grain filling stages after the AWDI-1 and AWDI-2 plots had been flooded for a long period the surface crust appeared to disintegrate and percolation rates increased greatly. A comparison of changes in S&P rates measured during the season indicates a much higher increase for DR-1 (225 % increase), AWDI-1 (85 %), and AWDI-2 (89 %) compared with the CF-1 (38 %) and CF-2 (13 %) plots (Table 3.4). The increase in percolation rate during the season for AWDI-2 was significantly (p = 0.05) higher than for CF-2. This indicates that percolation rates during the season were treatment dependent.

The difference in S&P rates for AWDI-1 (6.1 cm d^{-1}) < CF-1 (7.7 cm d^{-1}) at location 1 and AWDI-2 (6.8 cm d^{-1}) > CF-2 (5.3 cm d^{-1}) at location 2 during the reproductive and grain filling stages could account for the lower water savings (19% irrigation water saved) with AWDI–2 compared to what was observed with AWDI-1 (55 % water saved). The difference in irrigation applied for AWDI-1 and AWDI -2 during the reproductive and grain filling periods can be seen in the cumulative irrigation consumption curve (Figure 3.1) by the significantly steeper slope of AWDI-2 compared with AWDI-1.

Soil Moisture during Drying

Soil moisture measurements, taken several times during the vegetative growth period, show that minimum soil moisture, which was achieved several times during the season after several days of drying without rain, was about 80% saturation (0-30 cm depth) for the AWDI-1 and AWDI-2 plots. At this time cracks were 1-cm wide. DR-1 plots dried to 85% saturation by evening before irrigation on a couple of dry and sunny days. On average, during vegetative growth DR-1 plots remained between 90-100% saturated during the day and were flooded to 3-cm depth every evening.

Yield and Components of Yield

There were no significant differences ($p = 0.05$) in grain yield, number of panicles per m^2, percent spikelets filled, and thousand-grain mass between irrigation treatments for both locations (Table 3.5). Grain yields were about 5.7 t ha^{-1} for all treatments at location 1 while at location 2 AWDI-2 produced 3.7 t ha^{-1} and CF-2 produced 3.9 t ha^{-1}. DR-1 and AWDI-1 produced significantly more spikelets per panicle compared with

CF-1 but it did not result in a higher grain yield. Canopy filling was visibly lower in AWDI-2 than CF-2. Analysis of yield components reveals that AWDI-2 produced significantly higher total tillering. This was offset by significantly lower percentage of tillers producing panicles and lower spikelet formation per panicle compared with CF-2. The difference in grain yield of CF-2 and AWDI-2 was not statistically significant.

Table 3.5 Yield and Yield Components

Irrigation Practice	No. of Fertile Tillers	Percent Tillers Fertile	Spikelets per Panicle	Percent Spikelets Filled	Thousand-Grain Mass	Yield of Paddy Rice
Location 1	m^{-2}	%		%	g	t ha^{-1}
DR-1	247**a**[a]	72.9**a**	324**c**	79.7**a**	27.4**a**	5.73**a**
AWDI-1	223**a**	68.3**a**	290**b**	82.7**a**	27.3**a**	5.72**a**
CF-1	235**a**	74.0**a**	268**a**	78.7**a**	27.3**a**	5.70**a**
Location 2						
AWDI-2	188**a**	59.0**a**	253**a**	82.8**a**	27.3**a**	3.74**a**
CF-2	187**a**	70.7**b**	290**b**	84.4**a**	26.8**a**	3.90**a**

a.) Within columns, means followed by a different letter are significantly different at $p = 0.05$ Fisher's LSD test; calculated separately for locations 1 and 2.

Grain yields at location 2 were significantly lower (at $p = 0.05$) than location 1. These differences were primarily due to differences in soil fertility and organic matter content (Table 3.1) which resulted in the production of fewer tillers and panicles per m^{-2} on the less fertile soil of location 2 (Table 3.5). There also was a late-season attack of rice blast (panicular) at location 2, which resulted in lower spikelet formation and grain filling.

Water Productivity

Irrigation water productivity (water-use efficiency) measured as grain yield per mean irrigation water applied differed significantly between treatments (Table 3.6). Water productivity was in the order AWDI-1>DR-1>CF-1 at location 1. Irrigation water-use efficiency for AWDI-1 (0.30 kg m^{-3}) was twice that of DR-1 (0.15 kg m^{-3}) and more than double CF-1 (0.13 kg m^{-3}). The water-use efficiencies at both locations were relatively low due to the very high percolation rates of the terraced paddies. At location 2 there was not any significant difference in the water productivities of AWDI-2 and CF-2. Although, total irrigation water application for AWDI-2 was lower than CF-2, this was offset by lower grain yields in AWDI-2.

During vegetative growth DR-1 looked the healthiest and produced the most aboveground biomass, but that did not result in a similarly high grain yield. AWDI-1 produced the best harvest index (calculated as grain mass / total aboveground biomass), but it was not statistically different from the other treatments.

Table 3.6 Effect of Water Management on Plant and Water Productivity

Irrigation	Grain Yield		Harvest Index	Total Water Applied[a]		Water Productivity[a]	
Location 1	t ha^{-1}	Index[b] (%)		mm	Index[b] (%)	Grain kg m^{-3}	Grain + Straw kg m^{-3}
DR-1	5.73**a**[c]	101	0.49**a**	3823**ab**	91	0.15**a**	0.31**b**
AWDI-1	5.72**a**	100	0.52**a**	1899**a**	45	0.30**b**	0.58**c**
CF-1	5.70**a**	100	0.50**a**	4217**b**	100	0.13**a**	0.27**a**
Location 2							
AWDI-2	3.74**a**	96	0.49**a**	3256**a**	81	0.11**a**	0.24**a**
CF-2	3.90**a**	100	0.45**a**	4044**b**	100	0.10**a**	0.22**a**

a.) Statistical significance calculated with mean daily water application

b.) Index calculated based on CF-1 and CF-2 treatments separately for locations 1 and 2.

c.) Within columns, means followed by a different letter are significantly different at $p = 0.05$

Pests and Disease

Pest damage was high during the entire growing season. The most damage was caused by insects during the first two weeks after transplanting. Figure 3.2 shows the percent of young plants damaged after tranplanting. The AWDI-1 and AWDI-2 plots had the most damage with 48 % and 39 %, respectively, of the plants having to be replaced. Most of the young plants were attacked by soil-burrowing insects (including*Heteronychus Plebejus*, *Orthoptera Gryllotalpidae*) that remained from the previous off-season crop. These insects fatally cut the plants at ground level. The dry conditions in the AWDI plots were ideal for the insects and resulted in significantly ($p = 0.05$ for AWDI-1 and $p = 0.07$ for AWDI-2) more damage than in DR and CF plots.

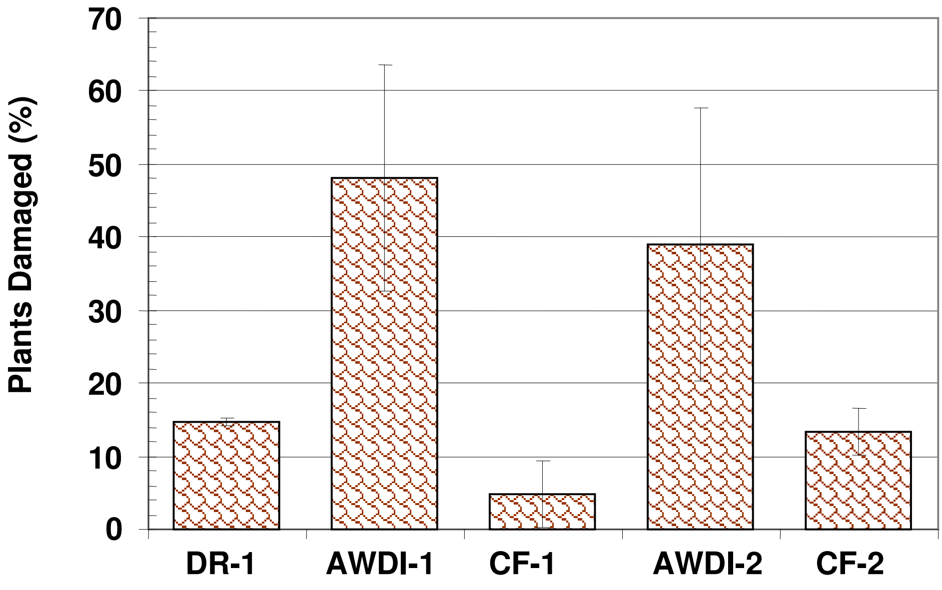


Figure 3.2 Pest Damage to Young Plants during Two Week Period after Transplanting. Vertical bars indicate one standard deviation from mean.

The daily flooding of DR plots reduced insect damage compared with AWDI plots. Continuous flooding (CF-1 and CF-2) minimized damage to young plants at both locations.

Locust crickets attacked all plots during most of the vegetative growth period. During reproductive growth, the plots at location 2 were attacked by rice blast fungus (*Pyricularia grisea*) which spread from adjacent upland rice fields. The plants were infected at the neck node and this resulted in yield loss.

Weed Growth

Sedges were the dominant weed type on all plots. Irrigation treatment significantly affected weed growth (Figure 3.3). The first weeding operation is not included because there were almost no weeds visible on all plots. During the second and third weeding operations, weed growth was significantly higher in the DR-1, AWDI-1, and AWDI-2 plots compared with CF-1 and CF-2. In terms of weed biomass, the difference between irrigation treatments at location 1 was not statistically significant, but in terms of weed population (in parentheses Figure 3.3) the differences were significant at $p = 0.05$. Weeds in the CF plots were larger and weighed more per plant because they had to grow from the soil layer up through the 5-cm of ponded water to be exposed to the atmosphere. This explains the small difference in biomass despite the significant difference in number of weeds. During the third weeding there were negligible numbers of weeds in the CF-1 and CF-2 plots. Continuous flooding effectively controlled weed population eliminating the need for a third weeding in the CF plots.

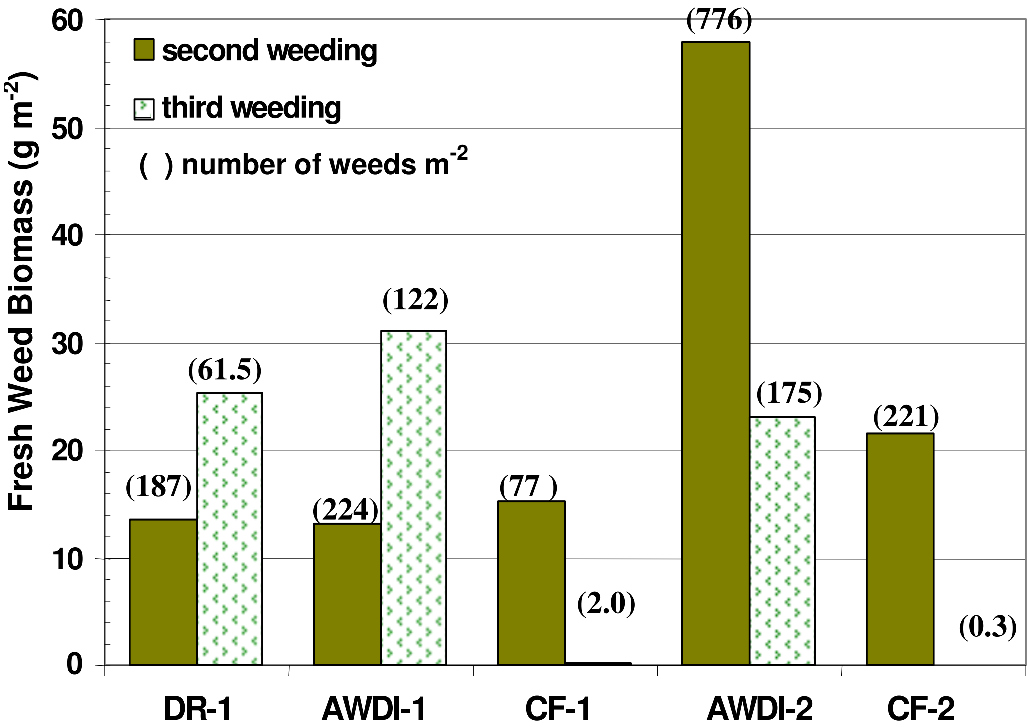


Figure 3.3 Weed Biomass and Population during Second and Third Weeding Operations

CONCLUSION

Results of this study suggest that alternate wet-dry irrigation during the vegetative growth period can be effective at reducing total irrigation water demand in rice paddies while maintaining high grain yields. The field trials, which were conducted at two adjacent locations on an experiment station in eastern Madagascar, produced similar grain yields for the alternate wet-dry and continuously flooded irrigation treatments at both locations. On the highly permeable soil of location 1, alternate wet-dry irrigation (AWDI) produced double the grain yield per unit of irrigation water compared with continuous flooding (CF) and daily rotational (DR) irrigation. Results from location 2, which had less permeable soils, indicated 19% water savings of AWDI over CF. However, water-use efficiency for AWDI and CF at location 2 were statistically similar indicating that a reduction in water use for AWDI was accompanied by a reduction in grain yield in the case of the less fertile soil.

Alternate wet-dry irrigation resulted in significantly more weed growth and pest damage compared with CF. Weed analysis indicated that AWDI and DR plots needed two weeding operations while CF plots only needed one. AWDI plots suffered significantly more plant damage caused by insects during the two-week period following transplanting compared with CF. Flooding in the CF plots limited damage from the ground-burrowing insects which were remaining from the previous off-season potato and bean crops. Successful implementation of AWDI by farmers will require good intensive weed and pest management.

CHAPTER 4

FARMER IMPLEMENTATION OF WATER SAVING IRRIGATION

ABSTRACT

Competition for limited water resources and low rice yields in developing countries has renewed the interest in finding better ways to grow more rice with less water. In recent years irrigation practices that limit the amount of water given during the vegetative growth stage have shown promise for reducing water consumption without significant effect on rice grain yield. In 2001, a survey of 109 farmers was conducted in four rice producing areas in Madagascar to investigate farmer implementation of water saving irrigation techniques recently introduced with the System of Rice Intensification (SRI). SRI recommends aerating the soil using alternate wet-dry or non-flooded irrigation during the vegetative development period and transplanting rice at a much earlier age and at a lower density than conventionally practiced. The survey showed that farmers have adapted their SRI practices to fit the soil type and their availability of water and labor. The primary drawbacks reported by farmers with implementing water saving irrigation were the lack of a reliable water source, little water control, and water use conflicts. SRI was associated with a significantly higher grain yield of 6.4 t ha^{-1} compared with 3.4 t ha^{-1} from conventional practices. On SRI plots, the grain yields were 6.7 t ha^{-1} for alternate wet-dry irrigation, 5.9 t ha^{-1} with non-flooded irrigation, and 5.9 t ha^{-1} for continuous flooding. The results of the study suggest that by combining water saving irrigation with SRI cultivation practices, farmers can increase grain yields while reducing irrigation water demand.

INTRODUCTION

Historically rice is cultivated under continuously flooded conditions in Madagascar. However, currently there are several thousand farmers throughout the island who practice alternate wet-dry (AWDI) and non-flooded (NF) irrigation during the vegetative stage of crop development. In this paper AWDI refers to the practice of regular cyclic flooding and drying, while NF includes practices by which the paddy is kept moist or saturated with no standing water. Some of these farmers practice AWDI or NF in combination with conventional cultivation methods due to periodic water shortage at the beginning of the rainy season. However, many Malagasy farmers have adopted these water saving irrigation practices as part of a new strategy of rice intensification, called SRI (System of Rice Intensification), which was developed in Madagascar in the 1980's. SRI recommends farmers combine these new water management practices with transplanting younger (8-12 day-old) seedlings at a lower plant density (25 hills per m^{-2} or fewer) and with fewer plants (one plant) per hill compared with conventional cultivation methods. The primary reason farmers apply SRI is to increase grain yields. Farmers have reported 50-200 % increase in yields without the use of chemical fertilizers (Uphoff 1999; Vallois 1996). Water saving is a secondary motivation.

The SRI irrigation recommendation is that farmers avoid keeping their paddy soil saturated during the vegetative growth period, making efforts to introduce some soil aeration, and then maintain continuously flooded conditions during the reproductive and grain-filling stages to promote better plant growth and increase grain yield. During the dissemination of SRI, extension agents recommend to farmers that they practice either AWDI or NF irrigation during the period of tillering until panicle initiation, after which they should keep the plot continuously flooded until 10-14 days before grain maturity and harvesting. In experimental trials conducted concurrently with the study reported here (see Chapter 3), this set of irrigation practices was found to require up to 55% less irrigation water compared with the conventional practice of continuous submergence during all periods. The productivity of water (calculated as grain yield per unit of irrigation water applied) for SRI was twice for AWDI (0.30 kg m^{-3}) compared with continuous flooding (0.13 kg m^{-3}) on the highly permeable (seepage + percolation >5 cm day^{-1}) terraced paddies used for the study.

This chapter presents the results of a survey that examined farmer adaptation, grain yields, and difficulties with AWDI and NF irrigation in Madagascar. Farmer implementation of these water saving practices is compared for the cases of SRI vs. conventional cultivation methods. For more detail on the SRI system, see Stoop et al. (2002).

METHODS

A survey was conducted during the rainy season February-June 2001 in Ambatondrazaka, Imerimandroso, Antsirabe, and Fianarantsoa with 40, 30, 28, and 11 farmers, respectively. Ambatondrazaka and Imerimandroso are located in the eastern province of Toamasina, while Antsirabe and Fianarantsoa are in the central highlands within the provinces of Antananarivo and Fianarantsoa, respectively. These sites are important rice producing areas and have a significant number of farmers (but, nevertheless, a small fraction of the total population of farmers at these sites) who practice SRI.

Farmers were selected from among those practicing both conventional (traditional) and intensive (SRI) rice cultivation. In the initial selection process, only farmers using the same rice variety for both systems were included. However, in the final number, a few farmers who used different varieties for their conventional and SRI plots (n = 7) were included in the study. The selected farmers were interviewed with a formal questionnaire about cultivation details and irrigation practices. Interviews were conducted in Malagasy by agricultural extension agents and university agronomy students during a minimum of three visits per growing season with each farmer. The interviewers were trained during pre-testing of the questionnaire at each location.

Most farmers had several plots on which they practiced numerous variations of conventional and intensive rice cultivation. For each farmer the survey collected agronomic and irrigation data for one plot cultivated with conventional and a plot with intensive practices. The plots were selected based on meeting at least two of the three criteria for classification of conventional and intensive (SRI) cultivation, the criteria being formulated after conducting preliminary interviews. Conventional methods were: transplant seedlings older than 20 days; three or more seedlings per hill; and with random plant spacing. For the intensive cultivation the criteria were: transplant seedlings less than 12 days old (not including direct seeding), one plant per hill, and planted in evenly spaced rows with plants in a square grid pattern. Water management practices were thus not made a defining characteristic of either conventional or intensive cultivation, but could vary within the sample of farmers. Where farmers had more than one plot that satisfied these criteria, the interviewer selected the one considered most representative of crop growth and plot size of that farmer.

In addition to the formal interviews, grain yield was measured from 2 x 2 meter quadrats during harvest time. All reported yields are calculated for paddy rice at 14% moisture content.

Statistical Analysis. The general linear model analysis of variance and Tukey's simultaneous test were used to analyze the association between farmers' irrigation practice and grain yield. These tests were chosen because they account for multiple factor variation. The analyses included geographic location, cultivation system, irrigation type, transplant age, plant hill density, plants per hill, nutrient additions or none, number of weedings, and soil type as factors that varied between plots. These factors produced a total R-squared value of 67%. Medians are reported instead of means in cases where data are highly skewed and the median better represents the average.

RESULTS

Sites and Environmental Conditions

Ambatondrazaka and Imerimandroso. Both locations are in the main rice-producing plain of Madagascar around Lake Alaotra (48°43'E, 17°83'S, 750 m above mean sea level). The soils are predominantly ferruginous clayey Aquepts, Aquents, and Fluvents formed by alluvial deposits from erosion of surrounding hillsides. Inherent soil fertility is fairly poor in all locations of the survey (Total N < 0.2%, Bray-II P < 10 ppm, K < 0.14 meq/100g) and was similar for both the SRI and conventional plots selected for the study (Barison 2002). Temperatures in the Lac Alaotra area are quite constant at 21-24^{o}C during the main cropping season from December to May. Rainfall amounts and distribution are very erratic from year to year. In recent years planting has been delayed due to the late arrival of rains. Average yearly rainfall is about 1025 mm (Figure 4.1).

Imerimandroso is situated on the northeastern side of Lake Alaotra about 60 km north of Ambatondrazaka, the main town in the region, which is on the southern side of the lake. The area is predominantly plains, but unlike the Ambatondrazaka area, a quarter of the study fields were situated in hilly areas.

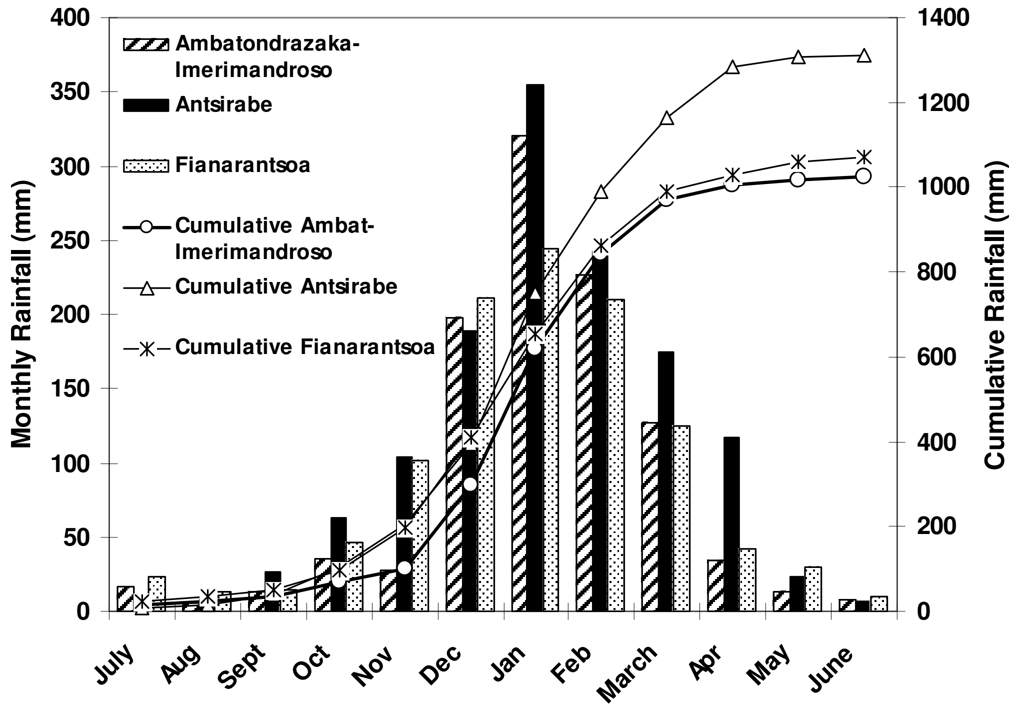


Figure 4.1 Average Monthly and Cumulative Rainfall, 1990-1999

(Source: Fofifa and Centre Metéorologique d'Ampasampito)

Antsirabe. This region surrounding the large city with this name is located in the highland (*haut plateau*) of central Madagascar (the city is located 48°03'E, 19°87'S, 1600 m above mean sea level). Soils in the study plots are volcanic and lowland alluvium (Aquepts). The landscape is mostly hilly with a few broad valley plains. Temperatures remain fairly constant at 18-20^{o}C during the main rice-growing season from October until April. Yearly rainfall averages 1310 mm.

Fianarantsoa. This region is located in the southern part of the *haut plateau* of central Madagascar (47°07'E, 21°45'S, 1500 m above mean sea level). Soils in the study plots are Oxisols and Aquepts with high clay content. The landscape is predominately hilly with terraced paddies. Temperatures remain fairly constant at 20-22^{o}C during the rice-growing season from December until May. Yearly rainfall averages 1070 mm.

Farmer irrigation practices during crop growth

Results of the survey show that over 80% of the SRI farmers selected for this study practice either AWDI or NF. Table 4.1 shows the percentage of the surveyed farmers using alternate wet/dry (AWDI), non-flooded (NF), and continuously flooded (CF) irrigation during each crop growth period. The following sections summarize farmer irrigation practices during crop development.

Table 4.1 Percent of Surveyed Farmers Using Alternate Wet-Dry (AWDI), Non-Flooded (NF), and Continuously Flooded (CF) Irrigation during each Period of Crop Growth

Growth Stage	Conventional			SRI		
	NF	AWDI	CF	NF	AWDI	CF
Nursery*	27	49	24	90	8	2
Vegetative*	1	16	83	30	53	17
Reproductive[ns]	0	5	95	2	5	93
Grain Filling[ns]	0	4	96	1	6	94
Maturity[ns]	45	0	55	43	1	56

* Irrigation practices significantly different for Conventional vs. SRI ($p = 0.01$, contingency table chi-square test).

ns = Not significantly different at 1% level

Seedling Stage. In the conventional nursery, farmers puddle a small plot and grow the seedlings under a layer of water, which increases in depth in proportion with plant height until time to transplant. However, a majority of the farmers interviewed in this study no longer practice CF in their nurseries (Table 4.1). Farmers said that AWDI and NF help with establishment of the seedling, promote better growth, and alleviate water shortage at the beginning of the rainy season. During informal discussions, farmers in Ambatondrazaka said that they use the SRI raised-bed, non-flooded nursery to supply seedlings for all their plots when they have insufficient water or seed to maintain conventional type nurseries. (SRI requires fewer seedlings than conventional cultivation because of lower transplant density.)

Vegetative Growth. Most of the surveyed farmers practiced AWDI or NF irrigation on their SRI plots (Table 4.1). 17 % of the farmers also practiced AWDI or NF on their conventional plot. In some cases this was due to water shortages while in other cases farmers said that they observed better tillering and plant growth during drainage of their SRI plots, so they also adopted the practice for their conventional plots. AWDI was used predominately in the Lac Alaotra area (Ambatondrazaka and Imerimandroso) while NF irrigation was the most common practice for SRI plots in Antsirabe and Fianarantsoa. This regional difference in adoption of AWDI and NF is due to differences in recommendation by extension agencies and farmer preferences. When SRI was first founded in the Antsirabe region in the 1980's, NF was the recommended type of irrigation. Over time and with the expansion of SRI in Madagascar extension agencies and farmers developed variations to these practices including some recommending AWDI in preference to NF irrigation.

AWDI irrigation schedules varied greatly between farmers. The schedules ranged from more frequent irrigation with 1 day flooding followed by 1 day drying to less frequent with 10 days flooding followed by 7 days drying. The median AWDI schedules for all farmers were 4 days flooded and then 5 days drying, with means of 4.4 days flooded and 4.8 days drying. On average, the farmers who practiced SRI in Antsirabe had a lower ratio of days flooded to days dry (1:2.4) compared with the Lac Alaotra area (1.1:1). During informal discussions farmers said that they developed their AWDI irrigation schedule based on their own time availability, soil type, observed rice response, water availability, and recommendations from extension agents.

In the Lac Alaotra area, many farmers decide their AWDI irrigation schedule based on observed soil cracking. Soils with higher clay content tend to crack faster. The differences in soil types could explain in part the large variation in AWDI irrigation schedules. Some SRI experts have recommended that farmers flood their plots every night and drain them the next morning. However, this study did not find any farmers implementing this schedule. During informal discussions farmers said that the amount of labor required to irrigate and drain daily makes that schedule impracticable. Farmers developed their own irrigation schedules that in their opinion produced the best rice growth and fit their labor and water availability.

Non-flooded irrigation (NF) was practiced on most of the SRI plots in Antsirabe and Fianarantsoa. Farmers said that they kept their soil moist or saturated with no standing water during the vegetative growth period. Moist soil conditions were maintained by passing water through the paddy without building up a layer of water. One farmer controlled soil moisture with a peripheral ditch around the edge of the paddy. This enabled him to regulate soil moisture by supplying and draining water from the peripheral ditch. Although this practice has been recommended by SRI experts, we found only one farmer implementing it.

Reproductive and Grain Filling Stages. Continuously flooded (CF) irrigation was practiced by more than 90% of the farmers during the reproductive growth and grain filling stages on both SRI and conventional plots (Table 4.1). Farmers said that these are the periods when the rice plant “needs the most water” and that it is essential to keep a layer of water on the paddy to produce high grain yield. Some farmers were not able to maintain flooded conditions because of lack of water availability and/or due to long water-sharing rotations.

Grain Maturity. Irrigation practices during grain maturity (yellow ripening) were similar for both conventional and SRI plots. Farmers prefer to dry their plots during this period to homogenize grain ripening. However, it is not always possible because so much irrigation is plot-to-plot. In this type of setup all available land area is placed in production with minimal or often no space saved for irrigation and drainage channels. Due to differences in planting time and rice variety, it is not possible for the rice in all the plots of the irrigation chain to reach maturity simultaneously. In order to maintain flooded conditions for plots that have not yet reached maturity, all the plots in the irrigation chain remain wet or flooded.

Cultivation Practices

There was a large variation in cultivation practices between farmers and between locations (Table 4.2). A comparison of practices by location shows similarities between Ambatondrazaka and Imerimandroso in the Lac Alaotra area and between Antsirabe and Fianarantsoa in the highlands. This was expected because of similarities in altitude, environmental conditions, landform, and geographic location. As seen in Table 4.2, there was more variation in conventional practices between locations than for the intensive (SRI) practices. This can be expected because SRI practices were recently introduced into these areas and have not had sufficient time for farmer modification and adaptation to differences in climate, soils, and socioeconomic conditions. In this study, average farmer experience with SRI was 2.3 years compared with an average of 16 years experience with conventional rice cultivation. On average, the conventional cultivation practices for farmers in this study consisted of transplanting 33-day-old seedlings with 3 plants per hill and 40 hills per m^{-2}, and one weeding during the season. Plots with SRI practices had younger transplants (10 days old), fewer plants per hill (one), fewer hills per unit area (24), and more weedings (2-3) during the season compared with the conventional plots. There was no significant difference in the number of farmers applying nutrients and growing off-season crops on their SRI plots compared with the conventional (Table 4.2).

The SRI method of cultivation recommends application of compost and manure rather than chemical fertilizer. This study found, however, that only a quarter of farmers who practice SRI were applying any nutrients to their fields; 5 farmers in Antsirabe, 7 in Fianarantsoa, and one in Ambatondrazaka used fertilizers while 25 used cattle manure and/or compost with their SRI crop. Most of the farmers applied the nutrients to their off-season crop and not directly for their rice crop. The common off-season crops were potatoes, beans, garden vegetables, and wheat. Over half of the surveyed farmers used chemical herbicides for weed control in the Lac Alaotra area. Farmers in this study used 13 different rice varieties, mostly improved indica and some japonica varieties. All except 7 of the farmers used the same variety for both their conventional and SRI plots. The difference between SRI and conventional yields for these farmers was similar to those who used the same variety for both systems.

On average, farmers allocated 29% of their total cultivated rice area (average total area per farmer was 0.8 hectares) for SRI practices. The difference in area cultivated with SRI and conventional practices could be due to the relative inexperience of farmers with the more recently adopted SRI practices. The high labor demand and higher risk associated with SRI may also limit the area that farmers can afford to cultivate (Barison 2002; Moser 2001).

Table 4.2 Farmer Cultivation Practices

Cultural Details	Ambatondrazaka		Imerimandroso		Antsirabe		Fianarantsoa		**Overall Mean**		
Cultivation System (Sample size, # of farmers)	SRI (40)	CONV (40)	SRI (30)	CONV (30)	SRI (28)	CONV (28)	SRI (11)	CONV (11)	**SRI** (109)	**CONV** (109)	**Differ ence** (109)
% Who Applied Fertilizer Within Past Year	3	0	0	0	18	21	64	18	**12**	**7**	**5**
% Who Applied Manure/Compost Within Past Year	10	5	0	3	46	64	73	18	**23**	**21**	**2**
Age of Transplant (DAS)[a,b]	9-11	26-31	9-11	29-33	9-12	41-48	7-13	18-33	**10**	**33**	**20-26****
Average Plant Hill Density m^{-2}	26	44	26	42	18	35	24	30	**24**	**40**	**11-21****
Average Seedlings per Hill[c]	1	3.3	1	3.5	1	2.8	1	2	**1**	**3**	**1.9-2.3****
Median Number of Times Weeded	2	1	2	0	4	2	2	1	**2.7**	**1.2**	**1.2-1.8****
% Who Applied Herbicide	38	48	0	93	0	0	0	0	**16**	**48**	**32***
% Cultivating Off-Season Crops within Past 3 Years	10	8	0	0	71	82	73	27	**29**	**27**	**2**

a = Days after seeding pre-germinated seeds
b = 95% confidence interval for mean
c = All farmers used 1 seedling per clump SRI practice except for one farmer in Antsirabe who used an average of 2.5 seedlings per clump
* Difference significant at p = 0.05; chi-square test with contingency table
** 99% confidence interval for difference in means; paired t-test

Grain Production

Analysis of grain yields indicated a large difference between the conventional and SRI plots (Table 4.3). The overall average SRI yield of 6.4 t ha^{-1} was significantly higher at the 1% level (paired t-test) than the 3.4 t ha^{-1} observed on conventional plots. At all locations grain yields for SRI were 70-90 % higher than conventional yields. The mean yield of 3.4 t ha^{-1} with conventional practices for farmers in this study is considerably higher than the national average of 2.03 t ha^{-1} for paddy rice in Madagascar (mean for 1998-2000, FAO 2000). This indicates that the farmers selected for this study who have adopted SRI and the water-saving practices of AWDI or NF are above average in their skills, their means of production, or possibly their soil quality.

Table 4.3 Mean Grain Yield for Conventional vs. Intensive Practices (t ha^{-1} paddy rice)

Location	Conventional Grain Yield	SRI Grain Yield	Difference in Yields*
Ambatondrazaka	3.4	6.7	2.4 - 4.2
Imerimandroso	3.4	6.7	2.8 – 3.8
Antsirabe	3.2	5.5	1.5 – 3.1
Fianarantsoa	3.4	6.3	1.3 – 4.6
Overall Mean	**3.4**	**6.4**	**2.6 - 3.4**

* 99 % confidence interval for difference in means; paired t-test

Table 4.4 presents the grain yields measured according to alternate wet-dry (AWDI), non-flooded (NF), and continuously flooded (CF) irrigation at each location. For yield analysis, plots were categorized as AWDI, NF, and CF based on the irrigation practice during the vegetative stage of crop development. Vegetative growth is the longest period during rice development and the main period when SRI irrigation differs significantly from conventional irrigation (Table 4.1). The plots with AWDI

Table 4.4 Summary of Yields by Irrigation Practice* and by Location (t ha^{-1})

Location	Conventional Plots			SRI Plots		
	CF	**NF**	**AWDI**	**CF**	**NF**	**AWDI**
Ambatondra-zaka	*3.38* (36)[1] 0.48[2]	-	*3.79* (3) 0.40	*6.40* (9) 2.2	*5.44* (9) 1.7	*7.37* (21) 1.9
Imerimandroso	*3.38* (16) 0.50	-	*3.46* (14) 0.41	*6.15* (1) 0	-	*6.74* (29) 1.2
Antsirabe	*3.23* (27) 0.57	*2.38* (1) 0	-	*5.61* (7) 1.4	*5.62* (13) 1.9	*5.12* (8) 1.4
Fianarantsoa	*3.38* (11) 0.39	-	-	*3.00* (1) 0	*6.69* (10) 1.4	-
Overall Mean[3]	***3.34*a** (90) 0.50	***2.38*a** (1) 0	***3.52*a** (17) 0.42	***5.89*ab** (18) 1.9	***5.91*a** (32) 1.8	***6.74*b** (58) 1.6

* Irrigation treatments are based on the irrigation practices during vegetative growth

1.) Sample size, number of farmers

2.) Standard deviation

3.) Yields followed by different letters are significantly different at 5% level irrigation produced the highest average yield in both the conventional and SRI plots. The highest mean yield of 7.4 t ha^{-1} was produced with AWDI and SRI cultivation practices in Ambatondrazaka. In the case of Antsirabe, AWDI produced a lower mean yield than both continuous flooding and non-flooded irrigation, however. This difference from what was observed at the other locations could be due to the soil type or difference in AWDI irrigation frequency (discussed above). For the SRI plots, the overall average grain yield for AWDI (6.7 t ha^{-1}) was significantly higher at the 5% level than for the NF plots (5.9 t ha^{-1}). However, due to the relatively small sample size and the high variation in farmer yields (see Table 4.4), the mean CF yield was not statistically different from AWDI or NF. For the conventional plots, there was no significant difference in yields between CF, NF, and AWDI.

Table 4.5 presents the statistical analysis of the combined grain yields for both conventional and SRI cultivation to look at the effects, ceteris paribus, of the different variables measured. The results indicate that cultivation system, geographic location, and soil type account for 28, 12, and 9%, respectively, of the overall variation in yields. Irrigation type during vegetative growth, nutrient additions or not, and transplant age were the important management factors accounting for 5, 4, and 3%, respectively of the overall variation in grain yields. The other management factors (plants per hill, plant hill density, and number of weedings during the season) did not have any statistically significant association with the grain yields. These results suggest that the difference in SRI and conventional yields is not due to any one management factor but is the result of a synergistic (collective) effect of SRI practices. There were no statistically significant interactions between the main factors. However, at $p = 0.07$ there was an interaction between cultivation system and soil type.

Table 4.5 General Linear Model Statistical Analysis of Grain Yield for All Plots, All Locations

Factor	**Adj SS**	**Adj MS**	**F**	**p-value**
Cultivation System (SRI vs. Conventional)	47.796	47.796	31.65	<0.001
Geographic Location	20.005	6.668	4.42	0.005
Irrigation Type	**9.440**	**4.720**	**3.13**	**0.046**
Soil Type	16.345	4.086	2.71	0.032
Nutrient Additions	6.965	6.965	4.61	0.033
Transplant Age	6.302	6.302	4.17	0.043
Plants per Hill	0.220	0.220	0.15	0.703
Plant Hill Density	0.145	0.145	0.10	0.757
Number of Weedings	8.508	1.215	0.80	0.584

Conventional yields were relatively constant for all soil types while SRI produced higher yields on clayey and organic soil than on loamy and sandy soil. A similar interaction was observed for irrigation and soil type. CF yields were constant for all soil types while AWDI and, especially, NF yields were higher for clayey and organic soil compared with loamy and sandy soil, which produced the lowest yield. Although statistically insignificant, these results suggest that there should be further research on the effects of soil type on SRI yields.

DISCUSSION

Considerations for farmer adoption of alternate wet-dry and non-flooded irrigation

The infrastructure and labor requirements for alternate wet/dry (AWDI) and non-flooded (NF) irrigation present difficulties for wide-scale adoption by farmers in Madagascar. In this study, 37 % of the farmers said that they have difficulties with AWDI and NF irrigation (Table 4.6). It is important to note that this percentage is probably lower than for the population as a whole since only farmers who are practicing SRI, and thus are more likely to have the necessary conditions for its implementation, were included in the study. Some of the special requirements for wide-scale adoption of AWDI and NF include a reliable water source, good water control, good social structures for water sharing, and available labor.

Reliable Water Source. Unreliable water source was the most common problem reported by farmers in the survey (Table 4.6). With AWDI, plots are drained and left to dry with the assumption that water will be available when needed at the end of the drying period. However, as seen in Table 4.7, most of the farmers in this study rely on stream flow as their irrigation source. At the beginning of the rainy season, which is during the vegetative growth period, stream flow is not reliable due to irregular rainfall, low base flows, and high demand of water for land preparation and crop irrigation. Farmers in Antsirabe and Fianarantsoa reported long periods when there was insufficient water to meet irrigation demand. This could be expected considering that over 75% of the farmers in those locations depend on direct rainfall and small stream flow for irrigation (Table 4.7). Construction of water storage devices is a possible means for creating more reliable water supplies.

Table 4.6 Problems that Farmers Reported with Applying SRI Water Management (AWDI or NF)

Location	Do you have difficulties with SRI water management?	Listed Reasons[a]		
		Little Water Control[b]	Unreliable Water Source	Conflict in Water Use[b]
	% (yes)	%	%	%
Ambatondrazaka	43	18	65	6
Imerimandroso	7	50	50	0
Antsirabe	46	8	31	61
Fianarantsoa	73	38	62	38
Total Average	**37**	**20**	**53**	**30**

a = Reasons given by farmers who say have difficulty with SRI water management

b = Includes both irrigation and drainage

Water Control. Lack of water control is another factor that prevents implementation of AWDI and NF irrigation in many parts of Madagascar. Large areas around Lake Alaotra are susceptible to flooding due to seasonal increase in the water level of the lake and to erosion and siltation of drainage canals. The broad valley plains and valley bottoms of Antsirabe and Fianarantsoa are also susceptible to seasonal flooding. Eight of the farmers practicing SRI in this study reported lack of water control as a difficulty. This number is relatively low because the localities selected for this study did not have the flooding problems experienced by many of the neighboring communities. Infrastructure needs to be built to control flooding and to permit drainage of Madagascar's major rice-producing areas before AWDI or NF can be widely adopted.

Water Sharing. A large percentage of farmers in Antsirabe and Fianarantsoa reported conflict over water use as a difficulty with AWDI and NF irrigation (Table 4.6). Over 60% of the plots in Antsirabe and Fianarantsoa are hillside terraces. Conventional irrigation for these is by cascade irrigation where water flows directly from plot to plot. This often leads to conflicts of interest in water management. Good social organization and/or construction of irrigation and drainage channels that allow for independent irrigation and drainage of individual plots are necessary to successfully implement AWDI and NF irrigation in such situations. Installation of irrigation and drainage channels in the hillside system could change the dynamics of the system because the sequential water-storage function of flooded paddies in plot-to-plot irrigation will be modified. Construction of on-farm reservoirs and coordination between farmers of the timing of flooding and drainage cycles are possible solutions to this problem.

Labor Requirements. It is worth noting that farmers did not list labor shortage as a primary difficulty with AWDI or NF. However, labor availability was a significant factor affecting farmers' decisions about the frequency of drying and flooding. With traditional continuous flooding, farmers in most cases simply adjust the outlet vane height to the desired flood depth and do not have to devote much time to irrigation after the beginning of the cropping season. However, AWDI requires that the farmer adjust and readjust the vane height to drain and irrigate on a regular basis.

Table 4.7 Irrigation Source Characteristics for Farmers in the Study

Location	**Type of Irrigation Source (% of farmers in study)**				**Farmers with Water Shortage**	**Duration of Period of Water Deficit[a,b]**	**Months of Water Deficit[a]**
	Stream	Dam	Reser-voir	None[c]	%	Days	Mode
Ambatondrazaka	47	47	3	3	45	30-41	Dec, Feb-March
Imerimandroso	60	30	10	0	30	0-31	Oct-Dec
Antsirabe	85	7	4	4	25	33-128	Oct-Dec, March
Fianarantsoa	23	13	14	50	82	31-44	Oct-Nov, Jan-Feb
Total Average	**54**	**24**	**8**	**14**	**45**	**37**	

a = Period during main rice growing season when water shortage is common

b = 95 % confidence interval for median

c = Irrigation from rainfall and direct drainage from other paddies that receive irrigation from rainfall

This can require a significant amount of labor depending on the number of plots that a farmer owns and how far apart the plots are from the farmer's home. NF may require even more frequent adjustments.

Another labor consideration for AWDI and NF is the extra weeding operations needed to control weed growth when there is no continuous flooding. CF is widely used to suppress weed growth. In Table 4.2, SRI cultivation was associated with an average of one to two more weeding operations during the season compared with continuous flooding. The labor required for the additional weeding operations could be difficult for farmers to commit during periods of labor shortage (for more information on SRI labor constraints see Moser 2001). Farmers need to take this into consideration when implementing AWDI or NF irrigation. For the farming operations covered by this study, Barison (2002) determined that the extra labor and costs for SRI compared with conventional cultivation are more than compensated for by the higher yields.

CONCLUSIONS

A survey of 109 farmers was conducted in four locations in Madagascar to explore farmer irrigation practices for conventional and intensive systems of rice production. Information was collected during formal and informal farmer interviews. Grain yield was also measured from one conventional and one SRI plot of each farmer. Results of the study revealed a wide variety of irrigation practices of farmers. With an average of 2.3 years of experience with alternate wet/dry (AWDI) and non-flooded (NF) irrigation, farmers have adjusted their irrigation schedules to fit their particular conditions.

Farmers base their irrigation schedule on many factors including crop response, soil type, and water and labor availability. Farmers reported lack of a reliable water source as the primary difficulty with practicing AWDI or NF. Inabilities to control water and conflicts over water use were also reported by many farmers. There was a significant association between irrigation practice and overall grain yields as AWDI produced higher grain yield than NF irrigation while continuous flooding was not significantly different from AWDI or NF irrigation.

Some of the solutions for wider-scale adoption of AWDI offered in this paper included developing more effective structures for water sharing, constructing irrigation and drainage channels, installing on-farm reservoirs, and building infrastructure for flood control. The 2-3 t ha^{-1} increase in grain yield observed in this study when AWDI is practiced in combination with SRI cultivation methods may justify these financial investments.

CHAPTER 5
CONCLUSIONS

The System of Rice Intensification (SRI) has shown promise of increasing the currently low rice grain yields in Madagascar while using less water. However, prior to the current study little was known about the actual water saving capacity of SRI irrigation practices and of farmer implementation of these water saving practices. An on-station experiment and an on-farm survey were conducted in Madagascar to determine the irrigation water savings, grain yields, and farmer implementation and difficulties with SRI irrigation.

Results of the experimental trials suggest that the SRI practice of alternate-wet dry irrigation during the vegetative growth period can be effective at reducing total irrigation water demand in rice paddies while maintaining high grain yields. On the highly permeable organic soil of location 1, alternate wet-dry irrigation (intermittent drying) produced double the grain yield per unit of irrigation water and used 55% less irrigation water compared with continuous flooding. Results from location 2, which had less permeable and less fertile soils, indicated 19% water savings of alternate wet-dry irrigation over continuous flooding. However, the water-use efficiency for intermittent drying and continuous flooding at location 2 were statistically similar indicating that a reduction in water use for alternate-wet dry irrigation was accompanied by a reduction in grain yield in the case of the less fertile soil. This suggests that the effect of SRI water saving irrigation on grain yield is soil dependent. In the on-station trials, SRI alternate wet-dry irrigation (AWDI) resulted in significantly more weed growth and pest damage compared with continuous flooding (CF). Weed analysis indicated that AWDI plots needed two weeding operations while

CF plots only needed one. AWDI plots suffered significantly more plant damage caused by insects during the two-week period following transplanting compared with CF. Flooding in the CF plots limited damage from the ground-burrowing insects which were remaining from the previous off-season potato and bean crops. Successful implementation of AWDI requires good intensive weed and pest management.

Results of the on-farm survey revealed a wide variety of irrigation practices of farmers. With an average of 2.3 years of experience with SRI water saving alternate wet-dry and non-flooded irrigation practices, farmers have adjusted their irrigation schedules to fit their particular conditions. Farmers base their irrigation schedule on many factors including crop response, soil type, and water and labor availability. Farmers reported lack of a reliable water source as the primary difficulty with practicing SRI irrigation. Inabilities to control water and conflicts over water use were also reported by many farmers. There was a significant association between irrigation practice and overall grain yields as alternate wet-dry irrigation produced higher grain yield than non-flooded irrigation while continuous flooding was not significantly different from either water saving practice.

Some of the solutions for wider-scale adoption of water saving irrigation practices in Madagascar offered in this thesis included developing more effective structures for water sharing, constructing irrigation and drainage channels, installing on-farm reservoirs, and building infrastructure for flood control. The 2-3 t ha^{-1} increase in grain yield observed in the on-farm survey when water saving irrigation is practiced in combination with SRI cultivation methods may justify these financial investments.

APPENDICES

Appendix 1. Data from On-Station Experiments

Table A.1. Seepage and Percolation Tests [1] (mm per day)

Plot No.	Veg 2/1/01	Veg 2/15/01	Reprod 3/8/01	Reprod 3/21/01	Reprod 3/22/01	Reprod 3/25/01	Milk 4/4/01	Milk 4/18/01
1		45.5	16.5	21.4	45.5		25.5	18.6
2	21.8		39.8	50.2	41.2		75.9	52.7
3	41.5		39.1	87.6	87.6		85.7	68.7
4		66.0	104.3	121.4	143.1		146.7	
5	23.9		47.9	62.8	30.9		57.9	42.1
6	26.0		35.8	107.1	120			150.7
7	45.0		99.4	57.4		85.5	72.2	
8		53.6	41.5	28.7		69.3		49.7
9		15.0	49.3	21.6		80.3	43.4	42.6
10	23.7		24.8	42.9		72.2	91.0	59.4
11	38.9		91.2	48.1		54.9		76.4
12		72.8	90.3	33.9		80.7	72.5	46.7

1.) The treatment for each plot is given in the plant productivity data table found on the next page.

Table A.2. Plant Productivity, Yield, and Total Irrigation Data

Plot Number	Treatment	Number of tillers per m^2	Number of fertile tillers per m^2	Average number of spikelets per panicle	Average number of spikelets filled	Average 1000-grain mass (g)	Average dry straw mass (g m^{-2})	Grain mass (g m^{-2})	Total water applied (mm)
1	CF-1	369	259	255.3	202.9	26.7	588	544	1500
2	DR-1	370	258	310.3	234.6	26.7	584	642	3183
3	AWDI-1	308	216	281.0	238.0	26.4	488	636	2261
4	CF-1	271	211	280.5	218.5	27.9	564	597	6934
5	AWDI-1	346	230	299.0	241.3	28.2	584	508	1538
6	DR-1	310	236	338.0	283.6	28.1	620	504	4463
7	AWDI-2	318	183	259.5	213.3	27.7	344	407	3649
8	CF-2	214	158	303.8	235.1	26.8	596	503	4160
9	CF-2	247	176	276.0	256.1	24.9	340	277	-
10	AWDI-2	337	195	246.0	209.1	26.7	424	343	-
11	AWDI-2	304	187	252.3	204.6	27.5	416	373	2862
12	CF-2	338	226	290.5	241.1	28.8	512	391	3929

Table A.3. Initial Soil Characteristics

Plot number	C (%)	Organic matter (%)	N (%)	C/N	Brays-II P (ppm)	K ($cmol_c$ kg^{-1})	CEC ($cmol_c$ kg^{-1})	pH 1:1 H_20
1	1.64	2.83	0.119	13.80	5.69	2.56	10.5	4.95
2	2.07	3.57	0.140	14.80	3.51	1.36	14.5	4.78
3	2.29	3.95	0.133	17.20	9.96	1.54	12.5	4.75
4	2.03	3.50	0.168	12.10	9.25	1.10	11.0	4.45
5	2.88	4.97	0.210	13.70	4.34	1.13	17.5	4.71
6	1.96	3.38	0.133	14.70	14.10	1.23	14.7	4.69
7	1.53	2.64	0.119	12.90	31.20	1.18	9.5	4.48
8	1.72	2.97	0.119	14.50	10.90	1.18	11.7	4.86
9	1.05	1.81	0.112	9.38	6.55	1.05	7.6	4.97
10	1.63	2.81	0.098	16.60	9.54	1.08	8.5	4.73
11	1.52	2.62	0.126	12.10	12.50	0.92	8.1	4.32
12	1.81	3.12	0.126	14.40	7.89	1.02	8.6	4.61

Table A.4. Weeds and Pest Damage

Plot Number	Treatment	Second weeding: average weed number per m^2	Third weeding: average weed number per m^2	Second weeding: average fresh weed biomass (g m^{-2})	Third weeding: average fresh weed biomass (g m^{-2})	Percent of young plants replaced due to insect damage (%)
1	CF-1	150	4	29.9	0.2	1.5
2	DR-1	291	113	18.5	44.5	15
3	AWDI-1	370	142	20.0	23.8	37
4	CF-1	4	0	0.5	0.0	7.9
5	AWDI-1	78	102	6.4	38.2	59
6	DR-1	82	10	8.4	6.3	14
7	AWDI-2	616	359	44.5	40.7	60
8	CF-2	135	1	41.2	0.2	12
9	CF-2	176	0	1.7	0.0	11
10	AWDI-2	1105	85	126.6	17.6	30
11	AWDI-2	608	82	2.7	10.9	27
12	CF-2	352	0	21.6	0.0	17

Appendix 2. SRI Water Management: Addendum to Chapter 4:

"Farmer Implementation of Alternate Wet-Dry and Non-Flooded Irrigation Practices in the System of Rice Intensification (SRI)"

Conclusions and Recommendations for SRI Water Management

Based on Farmer Survey Study 2000-2001 (See Additional Results Below):

1.) Alternate wet-dry irrigation (AWDI) produced higher grain yield than non-flooded (NF) irrigation
2.) AWDI produces as good as and potentially better yields than continuous flooding (CF)
3.) Water management is a significant factor/part of SRI
4.) SRI grain yields are more affected by soil type than conventional yields (SRI does better on organic and clayey soils than sandy and loamy soil while conventional yields are quite constant across soil types)
5.) Grain yields for AWDI and NF irrigation are more affected by soil type than CF is (On sandy soil there is probably not any difference in yields for AWDI, NF, and CF; on organic and clayey soils AWDI probably produces better yields than CF)
6.) In applying AWDI, farmers should probably limit the period the paddy is drained to 4 days or less since the farmers who kept their plots drained for less than the average number of days (4.5 days) got higher yields. There was also a general, but slight, trend to lower yields with longer periods of drying.
7.) Further research will need to be done to determine optimum duration of flooding and drainage cycles of AWDI for different soil types

Table A.5. Summary of Yields by Irrigation Practice* and by Location (t ha^{-1})

Location	Conventional Plots			SRI Plots		
	CF	**NF**	**AWDI**	**CF**	**NF**	**AWDI**
Ambatondrazaka	3.38 (36)[1] 0.48[2]	-	3.79 (3) 0.40	6.40 (9) 2.2	5.44 (9) 1.7	7.37 (21) 1.9
Imerimandroso	3.38 (16) 0.50	-	3.46 (14) 0.41	6.15 (1) 0	-	6.74 (29) 1.2
Antsirabe	3.23 (27) 0.57	2.38 (1) 0	-	5.61 (7) 1.4	5.62 (13) 1.9	5.12 (8) 1.4
Fianarantsoa	3.38 (11) 0.39	-	-	3.00 (1) 0	6.69 (10) 1.4	-
Overall Mean[3]	**3.34a** (90) 0.50	**2.38a** (1) 0	**3.52a** (17) 0.42	**5.89ab** (18) 1.9	**5.91a** (32) 1.8	**6.74b** (58) 1.6

* Irrigation treatments are based on the irrigation practices during vegetative growth

1.) Sample size, number of farmers

2.) Standard deviation

3.) Yields followed by different letters are significantly different at 5% level

Table A.6. General Linear Model Statistical Analysis of Grain Yield for All Plots, All Locations

Factor	Adj SS	Adj MS	p-value
Cultivation System (SRI vs. Conventional)	47.796	47.796	<0.001
Geographic Location	20.005	6.668	0.005
Irrigation Type	**9.440**	**4.720**	**0.046**
Soil Type	16.345	4.086	0.032
Nutrient Additions	6.965	6.965	0.033
Transplant Age	6.302	6.302	0.043
Plants per Hill	0.220	0.220	0.703
Plant Hill Density	0.145	0.145	0.757
Number of Weedings	8.508	1.215	0.584

Ranking of statistically significant factors according to % contribution to overall variation in combined Conventional and SRI grain yields:

1.) Cultivation system 28%

2.) Location 12%

3.) Soil type 9%

4.) Irrigation 5%

5.) Nutrient additions or not 4%

6.) Transplant age 3%

Other factors were not statistically significant.

Factor Interactions with Irrigation

(For combined systems)

Soil type x Irrigation → p = 0.16

Transplant age x Irrigation → p = 0.64

Plant density x Irrigation → p = 0.54

Plants per hill x Irrigation → p = 0.70

Cultivation system x Irrigation → p = 0.64

Cultivation system x soil type → p = 0.07

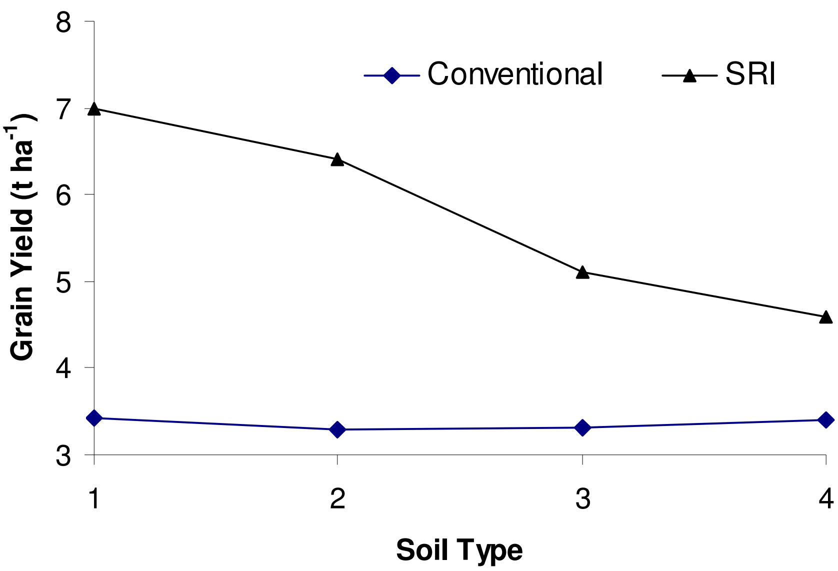


Figure A.1. Interaction of System and Soil Type on Mean Grain Yield

(Soil 1 = organic, 2 = clayey, 3 = loamy, 4 = sandy)

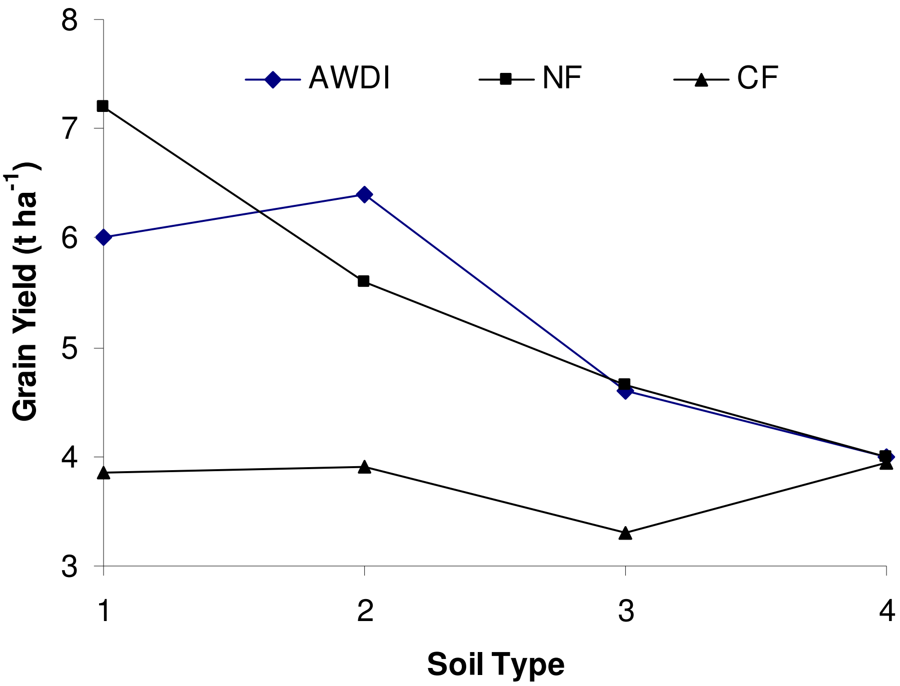


Figure A.2. Interaction of Irrigation and Soil Type on Mean Grain Yield

(Soil 1 = organic, 2 = clayey, 3 = loamy, 4 = sandy)

Tabulated Statistics: Irrigation, Soil

Rows: Irrigation Columns: Soil

	Clay	Loam	Organic	Sand	All
AWDI	35	8	28	2	73
	29.91	32.00	45.16	22.22	34.27
	16.43	3.76	13.15	0.94	34.27
CF	63	13	26	5	107
	53.85	52.00	41.94	55.56	50.23
	29.58	6.10	12.21	2.35	50.23
NF	19	4	8	2	33
	16.24	16.00	12.90	22.22	15.49
	8.92	1.88	3.76	0.94	15.49
All	117	25	62	9	213
	100.00	100.00	100.00	100.00	100.00
	54.93	11.74	29.11	4.23	100.00

Cell Contents --

Count

% of Col

% of Tbl

REGRESSION ANALYSIS OF SRI-AWDI GRAIN YIELD

Total number of farmers practicing AWDI on SRI plots = 58

Mean days drained = 4.5

Median days drained = 4

Mean days submerged = 4.0

Median days submerged = 4

Mean fraction of days submerged/days drained = 1.2

Median fraction of days submerged/days drained = 0.75

<u>Regression Analysis of SRI-AWDI Duration of Drainage</u>

Single factor analysis (Only significant at 10% level)

The regression equation is

t/ha Grain Yield = 7.65 - 0.183 days dry

56 cases used 2 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	7.6548	0.5200	14.72	0.000
days dry	-0.1833	0.1068	-1.72	0.092

S = 1.554 R-Sq = 5.2% R-Sq(adj) = 3.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	7.119	7.119	2.95	0.092
Residual Error	54	130.469	2.416		
Lack of Fit	5	3.581	0.716	0.28	0.924
Pure Error	49	126.888	2.590		
Total	55	137.588			

Multiple factor analysis (Regression significant but factor (days drained) not significant)

The regression equation is

t/ha Grain Yield = 10.2 - 0.154 days dry - 0.693 Location

- 0.020 Age Transplant - 0.0065 pl/sqm - 0.627 soil type

+ 0.083 Nutrient addtions

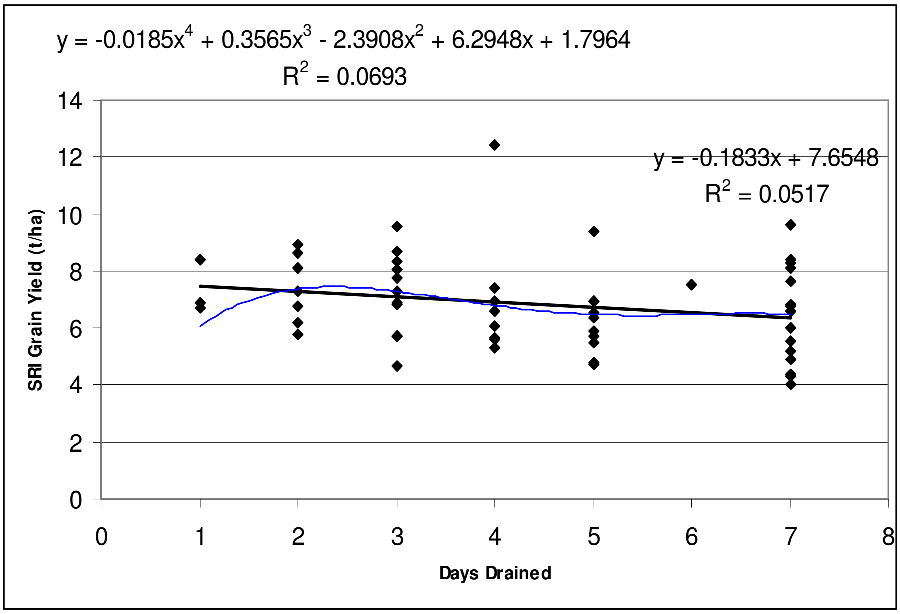
53 cases used 5 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	10.182	1.584	6.43	0.000
days dry	-0.1538	0.1085	-1.42	0.163
Location	-0.6929	0.3551	-1.95	0.057
Age Tran	-0.0200	0.1274	-0.16	0.876
pl/sqm	-0.00652	0.02448	-0.27	0.791
soil typ	-0.6274	0.2884	-2.18	0.035
Nutrient	0.0830	0.4771	0.17	0.863

S = 1.497 R-Sq = 23.2% R-Sq(adj) = 13.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	6	31.169	5.195	2.32	0.049
Residual Error	46	103.065	2.241		
Lack of Fit	44	102.340	2.326	6.42	0.144
Pure Error	2	0.725	0.363		
Total	52	134.234			



Thin line = 4^{th} order polynomial fit; Dark line = linear fit

Figure A.3. SRI-AWDI Grain Yield vs. Duration of Drainage

<u>**Regression Analysis of SRI-AWDI Duration of Flooding**</u>

Single factor analysis (Not significant)

The regression equation is

t/ha Grain Yield = 6.70 + 0.0251 days sub

55 cases used 3 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	6.6980	0.4278	15.66	0.000
days sub	0.02512	0.09224	0.27	0.786

S = 1.584   R-Sq = 0.1%   R-Sq(adj) = 0.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.186	0.186	0.07	0.786
Residual Error	53	133.025	2.510		
Lack of Fit	7	11.591	1.656	0.63	0.731
Pure Error	46	121.434	2.640		
Total	54	133.211			

Multiple factor analysis (days submerged not significant)

The regression equation is

t/ha Grain Yield = 8.89 - 0.0098 days sub - 0.726 Location

+ 0.053 Age Transplant - 0.0080 pl/sqm - 0.666 soil type

+ 0.199 Nutrient addtions

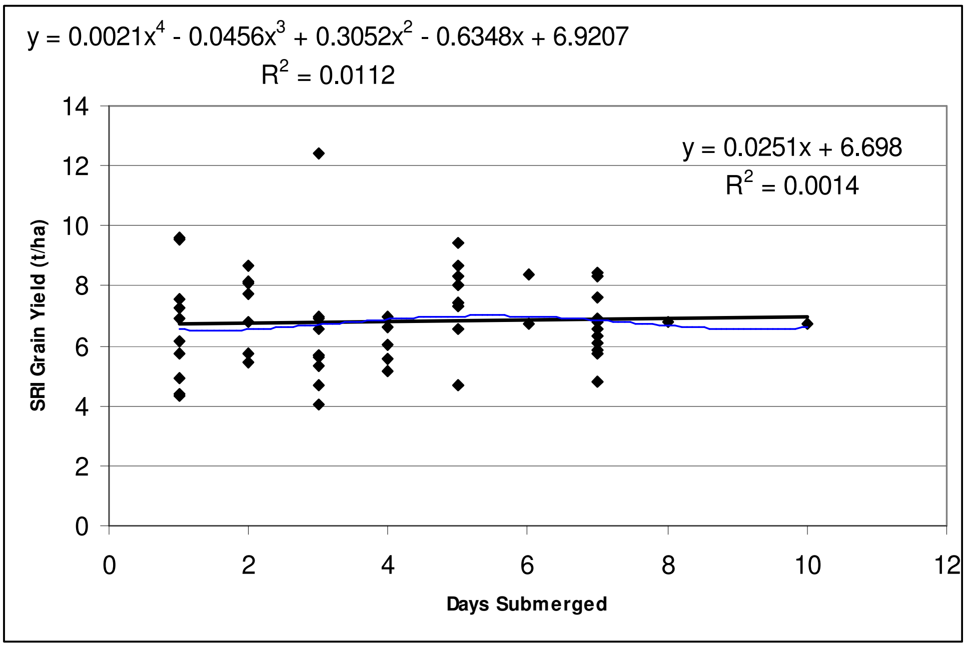
52 cases used 6 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	8.886	1.522	5.84	0.000
days sub	-0.00984	0.09374	-0.10	0.917
Location	-0.7262	0.3582	-2.03	0.049
Age Tran	0.0531	0.1284	0.41	0.681
pl/sqm	-0.00802	0.02508	-0.32	0.751
soil typ	-0.6656	0.2955	-2.25	0.029
Nutrient	0.1986	0.4843	0.41	0.684

S = 1.522 R-Sq = 19.9% R-Sq(adj) = 9.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	6	25.874	4.312	1.86	0.108
Residual Error	45	104.198	2.316		
Lack of Fit	44	104.193	2.368	473.60	0.036
Pure Error	1	0.005	0.005		
Total	51	130.072			



Thin line = 4th order polynomial fit; Dark line = linear fit

Figure A.4. SRI-AWDI Grain Yield vs. Duration of Flooding

Regression Analysis of SRI-AWDI Fraction of Days Flooding to Days Drained

Single factor analysis (Not significant)

The regression equation is

t/ha Grain Yield = 6.62 + 0.149 sub/dry

55 cases used 3 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	6.6233	0.2922	22.66	0.000
sub/dry	0.1488	0.1702	0.87	0.386

S = 1.574 R-Sq = 1.4% R-Sq(adj) = 0.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.895	1.895	0.76	0.386
Residual Error	53	131.316	2.478		
Lack of Fit	22	33.299	1.514	0.48	0.962
Pure Error	31	98.017	3.162		
Total	54	133.211			

Multiple factor analysis (Regression significant at 10% level but factor (fraction days sub/dry) not significant)

The regression equation is

t/ha Grain Yield = 8.88 + 0.146 sub/dry - 0.742 Location + 0.032 Age Transplant
- 0.0074 pl/sqm - 0.662 soil type + 0.214 Nutrient addtions

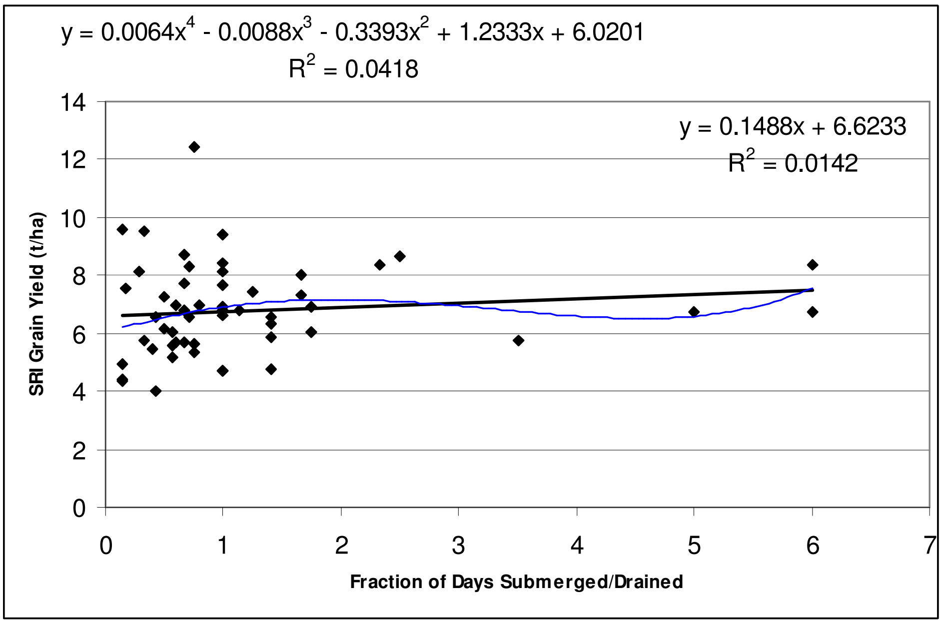
52 cases used 6 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	8.880	1.475	6.02	0.000
sub/dry	0.1457	0.1676	0.87	0.389
Location	-0.7421	0.3557	-2.09	0.043
Age Tran	0.0323	0.1294	0.25	0.804
pl/sqm	-0.00736	0.02473	-0.30	0.767
soil typ	-0.6620	0.2917	-2.27	0.028
Nutrient	0.2142	0.4781	0.45	0.656

S = 1.509 R-Sq = 21.2% R-Sq(adj) = 10.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	6	27.569	4.595	2.02	0.083
Residual Error	45	102.503	2.278		
Total	51	130.072			



Thin line = 4^{th} order polynomial fit; Dark line = linear fit

Figure A.5. SRI-AWDI Grain Yield vs. Fraction of Days Flooding to Days Drying

<u>Regression Analysis of SRI-AWDI Mean Flooding and Drainage Duration</u>

Mean days drained = 4.5

Mean days submerged = 4.0

> / <, greater and less than respective averages

on = submerged

off = drained

Codes to Interpret Analysis Below:

1.) > on < off, more than 4 days flooded and less than 4.5 days drained
2.) > on > off, more than 4 days flooded and more than 4.5 days drained
3.) < on < off, less than 4 days flooded and less than 4.5 days drained
4.) < on > off, less than 4 days flooded and more than 4.5 days drained

Descriptive Stats:

```
Level   N    Mean    StDev  ----+---------+---------+---------+--
1       11   7.307   0.965            (----------*-----------)
2       12   6.849   1.417        (-----------*----------)
3       17   7.057   1.883           (--------*---------)
4       15   6.093   1.549  (---------*---------)
                            ----+---------+---------+---------+--
Pooled StDev =  1.545          5.60      6.40      7.20      8.00
```

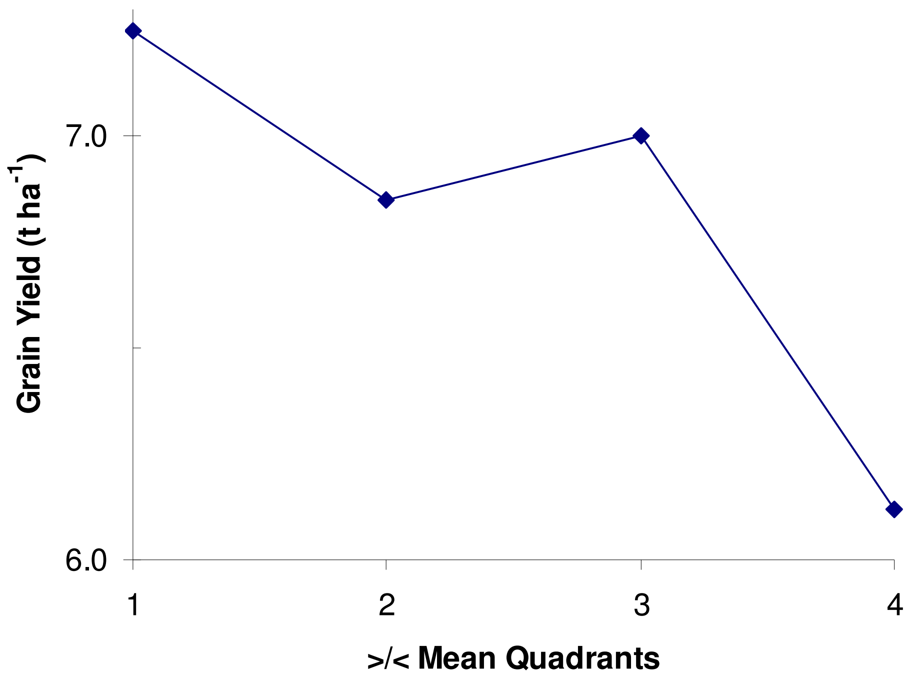


Figure A.6. SRI-AWDI Grain Yield vs. Flooding/Drainage Mean Quadrants

(See quadrant codes on previous page)

Single factor analysis (Only significant at 10% level)

The regression equation is

t/ha Grain Yield = 7.72 - 0.347 >/< average

55 cases used 3 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	7.7205	0.5494	14.05	0.000
>/< aver	-0.3472	0.1917	-1.81	0.076

S = 1.538 R-Sq = 5.8% R-Sq(adj) = 4.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	7.767	7.767	3.28	0.076
Residual Error	53	125.444	2.367		
Lack of Fit	2	3.707	1.853	0.78	0.465
Pure Error	51	121.737	2.387		
Total	54	133.211			

Multiple factor analysis (Regression significant at 10% level but factor (>/< average) not significant)

The regression equation is

t/ha Grain Yield = 9.68 - 0.231 >/< average - 0.692 Location

+ 0.023 Age Transplant - 0.0106 pl/sqm - 0.609 soil type

+ 0.160 Nutrient addtions

52 cases used 6 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	9.677	1.628	5.94	0.000
>/< aver	-0.2308	0.1985	-1.16	0.251

Location	-0.6916	0.3542	-1.95	0.057
Age Tran	0.0232	0.1290	0.18	0.858
pl/sqm	-0.01061	0.02462	-0.43	0.668
soil typ	-0.6086	0.2935	-2.07	0.044
Nutrient	0.1601	0.4764	0.34	0.738

S = 1.500 R-Sq = 22.2% R-Sq(adj) = 11.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	6	28.887	4.814	2.14	0.067
Residual Error	45	101.185	2.249		
Lack of Fit	41	85.706	2.090	0.54	0.862
Pure Error	4	15.478	3.870		
Total	51	130.072			

General Linear Model: Multiple factor (Not significant)

Analysis of Variance for t/ha Gra, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
>/< aver	3	11.401	5.201	1.734	0.75	0.529
Location	2	8.176	8.346	4.173	1.80	0.178
Age Tran	1	0.659	0.178	0.178	0.08	0.783
pl/sqm	1	1.182	1.969	1.969	0.85	0.362

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