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Assessment of environmental impact of Rain Catching and Controllable Irrigation regime in paddy field for sustainable agriculture in Nanjing, China.

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Abstract— In a healthy farm system, agriculture works in harmony with the natural environment. This begins with healthy soil that stores water, nutrients and provides a stable base to support plant roots. In a sustainable agriculture system, soil is kept in balance. To assess environmental impacts of Rain Catching and Controllable Irrigation on a paddy field, a study on the experimental field was performed during the growing season over a 2-year period. The plots were separated according to controllable irrigation schedule T2 (High dry low flooding) and T3 (High dry High flooding) rather than conventional irrigation regime T1 (Shallow and frequent irrigation). The mechanism of RCCI model showed its ability to reduce the water supply irrigation by 36% for T3 and 21% for T2, while T1 treatment provided to the rice plants 100% of its water requirements. The maximum use of rainfall by reducing surface drainage and percolation on the plots was the issue of the RCCI model. The results showed that T3 treatment got roots highest activities (285 µg/g.h), T2 treatment take the medium level of roots activities (247.26 µg/g.h), whereas T1 was the last one (226.66 µg/g.h) during the same rice growth period. The T3 treatment had present the half of nitrogen lost (9.17kg/ha) of the T1 treatment (20.28kg/ha). The RCCI model also reduces at least half phosphorus losses by reducing the volume of drainage water from 150.25mm (T1) to 84.14mm (T3). T3 treatment had a higher actual rice grain yield (7.56 T/Ha), and was a beneficial treatment with less environmental pollution. Pests in the paddy field were more important in 2011 than 2010. The weeds Echinochloa pyramidalis increased from 4plants/m2 to 9.5 plants/ m2. The rice yellow stem borer, Scirpophaga incertulas attacks were earlier and sterner in 2011 and caused a huge economic loss P= 10.39%.

Keywords — controllable irrigation, root activities, nitrogen and phosphorus loss, weeds *Echinochloa pyramidalis*, yellow stem borer *Scirpophaga incertulas*, rice yield loss.

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1 Introduction

United Nation's predictions of global population increase for the year 2025 require an expansion of food production of about 40-45%. Irrigation agriculture will be an essential component of any strategy to increase the global food supply[1].Without irrigation, increases in agricultural yields and outputs that have fed the world's growing population would not have been possible[2]. The number of irrigated land is constantly increasing with the development of various technologies through the world. Asia holds the bulk of the irrigated land with 37 percent of the land under cultivation in the region[3]. This is the highest level compared to the other major regions of the world. Democratic People's Republic of Korea has the highest level, with 73 percent of cultivated land under irrigation, followed by Japan with 65 percent and China with 55 percent (545,960 square kilometers). Most of China is unproductive agriculturally. Arable land is concentrated in a band of river valleys and along the southern and eastern coasts [4]. These rivers and valleys have been polluted by pesticide residues and fertilizers led by drainage water. Agriculture is the most source of pollution [5]; by Nutrients (phosphorus or nitrogen)[6] and pesticides [7],[8]. Reducing this pollution becomes a national concern.

Continuously rapid growth of domestic and industrial water uses, growing recognition of environmental demands for water, and the high cost of developing new water resources threaten the availability of irrigation water to meet growing food demands [2]. Because of that, each country has improved its irrigation techniques to reduce water supply to the crops without affecting their performance. So in China since the 1980s, the efficient irrigation regimes for rice have been researched, and many of those have been adopted in different rice growing regions, aiming to increase the water and land productivity [9], [10]. Also expansion of the irrigated area should be limited if water resources are to be conserved and the natural environment protected. In order to ensure the sustainable development of agriculture, especially food security, the future water-resources strategy must focus on changes in the agricultural water-saving technology to increase the effective use of precipitation and irrigation water[11]. Environmental considerations suggest that irrigation water supply for Chinese agriculture should be maintained at around 320–340 billion m3 a year. However, the state has suggested that the country must produce another 50 million tons of grain per annum by the year 2020. This suggests an increasing water requirement for agriculture [12] , whereas the climatic change disrupts the water regimes. The threat has led researchers to develop a large number of irrigation practices using less water such as Rain Catching and Controllable Irrigation, without considering the environmental consequences. Therefore, experimental evidence is still not reported in the international literature on the environmental impact of that irrigation regime adopted since five years.

The objective of the current study is to focus on the assessment of the environmental influence of Rain Catching and Controllable Irrigation model which has been in use (since 2006) in paddy fields in Nanjing, China. Its aim is to review different aspects of the environmental impacts of RCCI in areas relating to soil conditions improvement proven by root activities, such as total nitrogen and phosphorus loss in drainage water, and also on rice pests.

2 Materials and Methods

Experiment site and field soil conditions

The experiment was conducted from June to October 2010 and June to October 2011 at the Water Saving Park Agricultural Experimental Farm at Soil and Water Engineering Department at Hohai University in Nanjing, China. The farm is located at 31°95′N, 118°83′E, in a suburb of Nanjing at an area downstream of the Yangtze River drainage basin with an average elevation of 15 m above the sea level[13] . This area is characterized by a humid subtropical climate and is under the influence of the East Asia Monsoon. The mean annual temperature is 15.5 °C, with monthly mean ranging from 2.4 to 27.8 °C; the highest temperature in this area is 43.0 °C while the lowest is −16.9 °C. The average annual rainfall is 1062 mm. The soil at the experimental site is clayey loam (33.81%) clay (65%) silt 0.22%, and 0.97% (sand) with a pH (H_2O) of 8.06 and field capacity of 29.3; Table2.1 shows the physical and chemical properties of the field soil.

Table2.1: Soil physical and chemical properties

Soil texture		Clay
pH		8.06
Organic matter	（mg/kg）	12.26
Soil depth	(Cm)	0-20
Total phosphorus	（mg/kg）	330.9
Available P	（mg/kg）	10.13
N Total	（%）	0.1
Available nitrogen	（mg/kg）	65

During the growth season rainfall in 2010 from June to September was 580mm and the number of rainfall days for growth season of 2010 was 43days. During the growth season rainfall 2011from June to September was 601mm and the number of rainfall days for growth season of 2011 was 54 days. The average temperature and humidity during the growing season in this area are 30◦C and 79.75% respectively [14]

At this experiment, 1-month-old rice seedlings (Oryza sativa cv. Nanjing 44) were transplanted in June and harvested in September during 2010–2011. A fertilizer rate of 55, 45, 40, 10, 3 kg/ ha of N, P, K, S, Zn in the form of triple super phosphate, muriate of potash, gypsum and zinc sulphate, respectively were applied as basal dose at final land preparation following the local farming practices without spraying Insecticides and Herbicides.

Experimental design and treatments

The experimental design was based on the new concept of “Rain Catching and Controllable Irrigation (RCCI)” of rice[15]. Details of the design are shown in Table 2.2.

Table2.2: Experimental design of Rain Catching and Controllable Irrigation (unit: mm)

		RCCI model		TRI model
Treatments		T3	T2	T1
Growth period	Process	High dry High flooding	High dry Low flooding	Shallow and frequent irrigation
Seedling		10~30~70	10~30~70	10~30~70
Tillering	*Early -Tillering*	80%~100%~80	80%~100%~80	0~30~70
	Tillering	70%~100%~120	70%~100%~100	0~30~90
Stem elongation	*middle*	70%~100%~200	70%~100%~100	0~30~120
	Late	80%~100%~200	80%~100%~150	0~30~120
Heading		80%~100%~200	80%~100%~150	0~30~100
Milky stage		80%~100%~80	80%~100%~80	0~30~60
Ripening period		70%~80%	70%~80%	70%~80%

Note: (1) The three data, for example 10~30~70 respectively means the lower limit of irrigation, upper limit of irrigation and the maximum water-catching depth after rain in Table above; (2) Percentage means the percentage of the average moisture content of field capacity water content in the upper 30cm of soil and other units are mm. RCCI model: Rainfall Catching and Controllable Irrigation model; TRI model: Traditional Irrigation model or Conventional Irrigation schedule.

The experiment was conducted on the natural vegetation, which consisted of: *Poaceae* (*Echinochloa pyramidalis* , *Bromus sp, Dactylis glomerata, Digitaria ischaemum…); Typhaceae (Typha australis, T. latifolia, T. albida, T. alekseevii, T. angustifolia*); Fabaceae comprises three subfamilies (with distribution and some representative species): Mimosoideae, Caesalpinioideae, Faboideae; convolvulacea [16], [17].

Each plot measured 8 m long and 2 m wide, and was repeated four times in a completely random block design, the plants were transplanted on a scale of 0.2 m x 0.2 m giving a density of 250,000 plants per hectare with two plants per hill. In each plot, there were inserted pots; these pots had 80 cm of diameter and 60 cm of height with a content of 4 reference plants. The treatments applied on the plots were also applied to the pots. For this experiment, 1-month-old rice seedlings (Oryza sativa cv. Nanjing 44) were transplanted in May and harvested in September during 2010–2011summer. Cultivation regimes were consistent with optimum rice production in the region.

Water depth and soil moisture measurement

Soil moisture was measured at 0- 30 cm of soil profiles for unsaturated by Time Domain Reflectometer (TDR) and water depth in the field was measured by a ruler every 2-4 days interval.

Counting of weeds

Spatial distribution of weeds is characterized by weed density data collected at locations in a field (Density: Is a measure of abundance per unit area). The total number of weeds for all species was counted by adding emerging species every 5days. Emerging species are a newly established weed species whose extent, distribution and abundance is expanding (trend is increasing), and whose impacts are likely to be significant.

Absolute estimates of insects

Absolute estimates of the actual insect density are counted directly on the plant in time and space. An absolute estimate can be defined as a count of insect numbers with reference to a predefined unit of measurement. The count per unit measurement provides an estimate of insect density and can be recorded in terms of an unit area, plant or plant part, e.g. numbers of eggs per leaf, the number of larvae per plant, and the number of pupae per square meter[18].

Laboratory procedures of Phosphorus and Nitrogen determination

In the key Laboratory of Efficient Irrigation-Drainage and Agricultural Soil-Water Environment in Southern China, Hohai University, drainage water samples were analyzed by the standard methods of APHA (1995)[19] for total nitrogen(TN) and total phosphorus(TP) concentrations.

Estimated Mass loss =drainage volume × concentration (2.1)

Determination of rice roots activities

White roots were cut and 0.5g of the material (roots) was dried with a blotting paper. It was then put in a test tube and 5 mL of 0.4% Triphenyltetrazolium Chloride TTC ($\mathbf{C_{19}H_{15}N_4Cl}$) + 5 mL of (Buffer solution $\mathbf{NaH_2\ PO_4 / Na_2H\ PO_4}$) phosphate buffer at pH 7.0 added; the mixture was incubated at 37°C in water bath for 1hour.The reaction was stopped by adding 2 mL of 1mol/L $\mathbf{H_2SO_4}$. The roots after drying it with the blotting paper, was grinded in the mortar with 3 to 4 mL of Ethyl acetate ($\mathbf{C_4H_8O_2}$) and adding Ethyl acetate ($\mathbf{C_4H_8O_2}$) to get 10 mL. The samples were then centrifuged at 4000 revolutions per minute (r.p.m) into the sterilization machine (Anke TDL80-2B) for 4min. Use 10mL of Ethyl acetate ($\mathbf{C_4H_8O_2}$) in one test tube for the control (2 ck) and the absorbance of the supernatant measured at $\mathbf{A_{485}}$ nm in the spectrophotometer. The Formula below was used for the calculations: Triphenyl Tetrazolium Formazane **(TTF).**

TTF (µg) = 789.45 A_{485} + 7.3712.

Roots Activities (µg/g.h) = TTF/ sample fresh weight.

Water Use Efficiency (WUE)

According to Barrett Purcell & Associates (1999) [20] instead of Water Use efficiency it is in fact better to use the term Water Use Indices.

Evapotranspiration and Crop Water Use Indices (WUI)

ET (Evapotranspiration) was measures by the plastic pots buried in each plot. The size of the pots was 80cm in diameters and 60cm in height. The plant density kept same as that in field. The moisture was kept the same as that of the field.

Total water consumption (W_C) of rice was measures by difference of water depth or water moisture (if there was no surface water in the field or in the pots of the top soil 30 cm). Percolation can be calculated as follows:

$$\boldsymbol{P_1} = W_C - P - I + R + D \qquad (2.2)$$

Where P is precipitation (mm), I is irrigation water amount (mm), R is runoff/ run-on (mm), Runoff was considered zero because the experimental plots were surrounded with dikes and D is surface drainage (mm) amount from paddy field. P_1 (mm/day) is the percolation amount of water from the root zone.

Irrigation water use indices (WUI)

$$\text{WUI (Kg/ML)} = \frac{yield}{\text{Irrigation water applied}} \qquad (2.3)$$

$$\text{Crop WUI (Kg/mm)} = \frac{yield}{ET} \qquad (2.4)$$

Where: ML: Mega Liter = 1 000 m^3, ET=Evapotranspiration

Calculation of crop yield loss

Yield loss modeling is based on a set of concepts that were developed within the last two decades by FAO (2005)[21] on production ecology and plant protection. The main principles of this method are:

C = nuisance factor: $\mathbf{C = (a-b) * 100/a}$ (2.5)

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P=percentage of economic loss: **P= C*Ip/100** (2.6)
where a = average yield per non infested plant, **b** = average yield per infested plant and **Ip** = percentage of infest plants.

Statistical Analysis

Treatment effects in the experiment were analyzed through using analysis of variance (ANOVA) procedure of SPSS software Version 14.0. Average treatment were separated by Least Significant difference (LSD) test at $p \leq 0.05$ unless specified. Also, Excel and Orign8 were used for data analysis as well as plotting graphs and figures.

3 Results and discussions

Mechanism of Rainfall Catching and Controllable Irrigation in paddy field

Rice Evapotranspiration and Percolation quota reduction of RCCI

The Table 3.1 below shows Evapotranspiration and Percolation rate under RCCI model. The RCCI model has reduced the evapotranspiration from 37.73% by T3 and T1 treatment to 25% by T2 and T1 treatment. These results confirm those of Mao and Cui (2001) which show a reduction of Evapotranspiration from 5 to 30% of controllable irrigation. Under RCCI model, most of the time the average soil moisture content in the rice root zone (0-30cm) was in 70%-80% of field capacity. This leads to the average soil moisture content in 0-5cm of the surface layer to the level of below 50% of field capacity. Under this condition, the rice growth is not affected but the evaporation from the soil in paddy field can be reduced by about 10-20%[22].

Table3.1: Evapotranspiration and Percolation quota in the paddy fields

Treatments	ET(mm)	I (mm)	D (mm)	P1 (mm)	Effective rainfall(mm)
T1	672.21a	603.6a	150.25a	676.2	450.75
T2	504.21b	480.5b	102.17b	673.05	498.83
T3	418.58c	386.4c	84.14c	646.8	516.86

In the column, averages followed by the common letter(s) are not significantly different at level of P≤5%.

The reduction of percolation of RCCI model results from two ways: (1) The duration of no water depth and unsaturated condition in the paddy field is longer under RCCI than that under conventional irrigation schedule (T1); (2) The depth of water depth is shallower under RCCI than that under Traditional Irrigation. Under RCCI, the percolation was reduced due to the above-mentioned two conditions; Table 3.1 confirms that with T3 treatment which had the lowest (646.8mm) percolation rate P1.

Increasing rainfall utilization of RCCI

The intent of Rainfall Catching and Controllable Irrigation (RCCI) concept is to reduce as much as possible water supply for irrigation while using the maximum rainfall (Table 3.1). It means that irrigation will come in complement to avoid the water stress to the plants. Though the lower limits of RCCI are similar to those of T1, the rain-catching depth of RCCI was much higher than those of conventional irrigation. The capacity of paddy fields to store rainfall is increased greatly, and precipitation is fully utilized without hindering rice growth under RCCI.

Table3.2: Irrigation quota in the paddy fields unit: mm

Treatments	T1	T2	T3
Seedling	80.32a	67.5b	60.06c
Tillering	100.4a	90.5b	71.28c
Elongation	120.72a	92.6b	77.28c
Heading	120.72a	98.4b	77.28c
Milk stage	181.44a	131.5b	100.5c
Amount Irrigation	603.6a	480.5b	386.4c
Irrigation Schedule (Times)	14a	10b	10b

In the row, averages followed by the common letter(s) are not significantly different at level of P≤5%.

According to the treatments applied, the least irrigation water delivery in the field that data revealed in T3 which (386.4mm) has high control over rainfall water storage; followed by T2 (480.5mm) and T1 got the highest irrigation water delivery in the field (603.6mm) according to the controllable irrigation regime schedule as shown in Table 3.2.

Water Use Efficiency by RCCI model

The Crop Water Use Indices (Crop WUI**)** for the T3 treatment (18.06Kg/mm) was the highest whereas T1 (control) produce only 9.97 Kg/mm. T3 treatment used 1Mega Liter of irrigation water to produce rice grain yields of 1.95 tons, whereas the control T1 used the same amount to produce 1.11 tons. The RCCI model used efficiently water input (rain and irrigation) for grain production, which is significantly different (P≤5%) from the conventional irrigation. Under T3 treatment crop productivity was the highest and most efficient water use.

Table3.3: Crop Water Use Indices

Treatments	T1	T2	T3

Yield (Kg/Ha)	6700a	6630a	7560b
Irrigation (ML)	6.036a	4.803b	3.864c
ET (mm)	672.21a	504.21b	418.58c
Irr. WUI (Kg/ML)	1110.01a	1380.39b	1956.52c
Crop WUI (Kg/mm)	9.97a	13.15b	18.06c

In the row, averages followed by the common letter(s) are not significantly different at level of P≤5%.

The causes of the reduction of irrigation water requirements by using RCCI are that the percolation and evapotranspiration decreased remarkably while the utilization of rainfall increased as shown in Table3.1. T1 (conventional irrigation)treatment provided 100% of rice plant water requirements while T2 and T3 (RCCI)treatments provided only 79% and 64%,respectively,without reducing the grain yield. RCCI had saved 215.07 mm of water for the T3 treatment and 120.97 mm for T2 treatment.

Treatment T3 used 554L of input water to produce 1kg of rice grain while T2 treatment used 760L. According to Zwart and Bastiaansen (2004), an average water of 2,500 liters needs to be supplied (by rainfall and/or irrigation) to a rice field to produce 1 kg of rough rice. These 2,500 liters account for all the outflows of evapotranspiration, seepage, and percolation. The average number is derived from a large number of experimental data at the individual field level across Asia[23]. So, RCCI model saved 1946L and 1740L for treatment T3 and treatment T2, respectively.

Rice production must be viewed in the light of the emerging water crisis, as climate-change-induced shifts in rainfall patterns combined with the diversion of irrigation water for urban and industrial uses.

Environment protection of RCCI technic

RCCI Improves soil conditions in paddy field

Root activities during the main steps of rice cycle are used to assess soil conditions under the RCCI model and conventional irrigation. Results showed that roots activities increased with the development of rice plants (Table 3.4) under Controllable Irrigation conditions and declined with ageing plants. Rice roots activities were high in T3 (High dry High flooding) in every rice growth stage, from 225.86µg/g.h at tillering stage, 285 µg/g.h at elongation stage to 54.05 µg/g.h at rice milk stage. Under treatment T1 roots activities are lowest in almost all growth stages of rice from (184.22 µg/g.h) tillering stage to 39.38 µg/g.h at milk stage. Treatment T2 got the medium level of roots activities during the same period. Treatment T3 had the average longest roots 29.50cm and treatment T1 had the average shortest roots 21.25cm. In waterlogged soil (T1), diffusion of gases through soil pores was so strongly inhibited by their water content that it fails to match the needs of roots growing. A slowing of oxygen influx is the principal cause of an injury to roots, and the shoots they support [24]. The maximum amount of oxygen dissolved in the floodwater in equilibrium with the air is a little over 3 % of that in a similar volume of air itself. This small amount of oxygen is quickly consumed during the early stages of flooding by aerobic micro-organisms and roots. In addition to imposing oxygen shortage, flooding also impedes the diffusive escape and/or oxidative breakdown of gases such as ethylene [25]or carbon dioxide that is produced by roots and soil micro-organisms. This leads to accumulations that can influence root growth and function. Traditionally, a proper rate of deep percolation is maintained to leach the poisonous matters within rice root zone, resulting from an anaerobic condition and bring oxygen into rice root zone. The longer the duration of the soil submerged by deep water, the lower is the content of dissolved oxygen in soil water. These hydromorphic conditions reduce significantly (P≤5%) the rice roots activities as shown in Table 3.4

Table3.4: Rice roots activities under Controllable Irrigation conditions

Growth stages	Treatments	Root length (cm)	Roots activities (µg/g.h)
Tillering stage (35DAT)	T1	20	184.22a
	T2	21.25	209.88b
	T3	22	225.86c
Elongation (50DAT)	T1	21.25	226.66a
	T2	21.75	247.26b
	T3	23.25	285c
Heading (65DAT)	T1	21.70a	88.23a
	T2	21.81a	133.83b
	T3	25.25b	152.51c
Milk stage (80DAT)	T1	21.25a	39.38a
	T2	21. 75a	39.77a
	T3	29.50b	54.05b

In the column, averages followed by the common letter(s) are not significantly different at level of P≤5%.

The action of micro-organisms can be promoted and the accumulation of poisonous substances in the soil can be avoided by the favorable soil aeration. The microorganisms in the soil under RCCI model are more abundant than those under conventional irrigation. The soil fertility can be increased through the transformation of organic matter by the abundance of important microorganisms. The rice roots grow well under oxidized paddy fields even under moderate water stress, 29.5cm for T3 treatment was a proof.

Drainage and minerals (Nitrogen and Phosphorus) lost under RCCI model

The results in Table 3.5 showed the amount of drainage water during the whole growing period of rice. The smallest amount was observed in T3 plot 84.14 mm whereas T1 plot showed the largest amount 150.25 mm. The drainage water during the seedling period was less than the other phases of rice development for all the treatments. Tillering period for all the treatments had the biggest drainage water amount.

Table3.5 : Drainage in the paddy fields unit: mm

Growing period	T1	T2	T3	Total
Tillering	50a	34b	42.07c	126.07
Stem elongation	50.16	34.1	-	84.26
Heading	-	-	42.07	42.07
Milk stage	50.08a	34.05b	-	84.13
Amount of Surface drainage	150.25a	102.17b	84.14c	336.56
Frequency of drainage (Times)	3	3	2	-

In the row, averages followed by the common letter(s) are not significantly different at level of P≤5%.

Most of nitrogen loss is associated with the combination of excessively wet soil, the results in Table 3.6 show the estimated mass of total nitrogen loss in drainage water volume. Total nitrogen is composed of three forms of nitrogen, which are mainly found in soil drainage solution, namely, NH_4–N, NO_2–N and NO_3–N; that estimated mass of total nitrogen loss was increased gradually and doubled with the drainage volume, from T3 (9.17 kg/ha) to T1 (20.28 kg/ha). The RCCI model by reducing the volume of drainage water reduces also total nitrogen loss.

Table3.6 : Total Nitrogen loss in paddy fields

Treatments	Average concentration (mg/L)	Total drainage Volume (m3/ha)	Estimated mass of T N loss (kg/ha)
T3	10.9	841.4a	9.17a
T2	13.7	1021.7b	13.99b
T1	13.5	1502.5c	20.28c

In the column, averages followed by the common letter(s) are not significantly different at level of P≤5%.

The results in Table 3.7 below show the estimated mass of phosphorus loss under these three treatments. The control T1 had lost four times (0.648kg/ha) phosphorus more than T3 (0.149 kg/ha).While the phosphorus loss under the T2 treatment (0.32 kg/ha) was half of that cause by T1 treatment. The RCCI model reduces at least half phosphorus losses by reducing both volume of drainage water and concentration of TP.

Table 3. 7 : Phosphorus loss in paddy fields

Treatments	Average concentration (mg/L)	Total drainage Volume (m3/ha)	Estimated mass of P loss (g/ha)
T3	0.18	841.4a	151.45a
T2	0.32	1021.7b	326.94 b
T1	0.43	1502.5c	646.08c

In the column, averages followed by the common letter(s) are not significantly different at level of P≤5%.

According to Weining, (1993), alternate flooding and drying can reduce 20% to 65% of the percolation and seepage water from rice fields [26] and Fertilizer loss is brought about by this way of infiltration and drainage. This confirms the results of Table: 3.6 and Table: 3.7 that show the reduction of total nitrogen and phosphorus loss in the drainage water by the RCCI treatment regarding to the conventional irrigation. The higher rain-catching depth under RCCI weakened kinetic energy of raindrops thus decreased turbulence of surface water. That prevented the amount of topsoil particles rich in particulate N and P as well as soluble N and P, to enter into surface water. By this way RCCI reduced soil erosion. Additionally, the increasing of rain-catching depth also prolonged residence time of rain water in paddy field, and thus promoted deposition of soil particles, absorption of plants and soil, as well as nitrous nitrification and de-nitrification, which could reduce concentrations of TN and TP in surface water.

Pests in paddy field under Controllable irrigation regime

Weeds in the paddy fields

Weeds are common in transplanted wetland rice and they are highly competitive to the crop [27]. The occurrence of weeds has become a serious problem and they limit the yield and quality of crops. It is often stated that some weeds cause total crop failure and that weeding practices are absolutely essential [28], [29]. Optimum yields can be obtained only when the crop is free from weeds. Consequently, weed control has always been a major input in rice production. Under alternation of drying and flooding conditions, some species of weeds have been emergent, the hydromorphic conditions with more or less water layer reveal another kind of weeds.

Several genuses and species of weeds have been identified in plots; Table 3.8 and Table 3.9 give the detail. However, in 2011, we focused our attention on *Echinochloa pyramidalis* species.

Table3.8: Major rice weeds in the paddy fields (2010)

Weed species	Density in different plots (plant/m2)		
	T1	T2	T3

Echinochloa pyramidalis	4.0a	1c	1
Cyperus spp	2.0b	0.4d	0.7
Commelina diffusa	1c	0.2d	0.4
Marsilea quadrifolia	1c	0.2d	0.5

In the column, averages followed by the common letter(s) are not significantly different at level of P≤5%.

Table 3. 9 : Major rice weeds in the paddy fields (2011)

Weed species	Density in different plots (plant / m2)		
	T1	T2	T3
Digitaria ischaemum	1a	1a	4a
Cyperus difformis	3b	1a	0.7b
Commelina diffusa	1a	1a	1b
Marsilea quadrifolia	1a	0.2b	0.5b
Dactylis glomerata	2ab	2c	1b
Polygonum lapathifolium	1a	1a	1b
Alamo rental	1a	1a	1b

In the column, averages followed by the common letter(s) are not significantly different at level of P≤5%.

One reason for flooding rice is to manage a broad spectrum of terrestrial weed species that are sensitive to flooding. Flooding effectively controls many problematic weed species [30]. Total weed density and number of weed species were higher in 2011 (Table 3.10) than in 2010 (Table 3.9). It appears that sufficient accumulation of surface water in paddy fields can prevent germination and growth of many weeds under the treatments T1 and T2. The dominant weed species in the field can be regrouped in two types as shown in the Table 3.9, the Poaceaes and the Cyperaceae. The Poaceaes (*Digitaria ischaemum 4* plants / m^2) dominate the drier plots T3 treatment, the Cyperaceae (*Cyperus difformis*), with 3 plants / m^2 are abundant on the wetter plots T1 treatment. Also it is notable that the species found in both species and the two conditions (*Commelina diffusa*, *Polygonum lapathifolium* and *Alisma orientale*) of all treatments.

Insect in the paddy field

The figure 3.1 below shows the number of rice plants infested by yellow stem borer Scirpophaga incertulas in 2010. The attacks of (Scirpophaga incertulas) were observed from the 60 DAT and reach the peak in the 100 DAT with a maximum of 45 plants counted in the treatments T3.

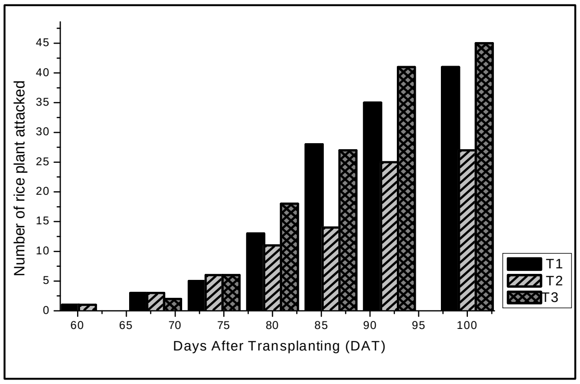

Figure3. 1: Number of rice plant attacked (2010)

The Figure 3.2 by tale makes a link between the density of the weed *Echinochloa pyramidalis* and the infestations of the rice plants by the yellow stem borer (*Scirpophaga incertulas*) in 2011.

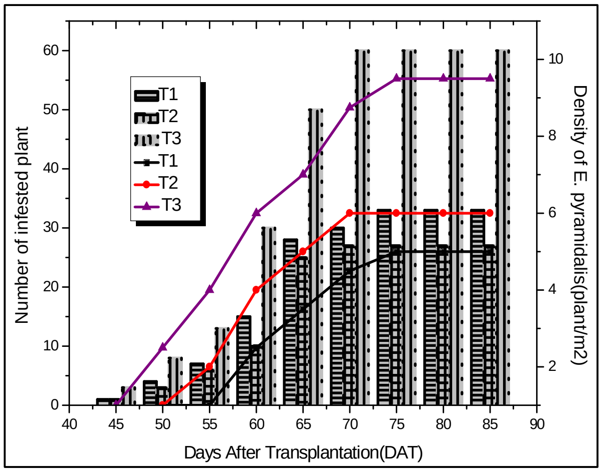

Figure3. 1: Number of rice plant attacked 2011and *E. pyramidalis* density

Figure 3.2 showed first that all treatments have been infested by the weed *E. pyramidalis*, but in different densities (P ≤5%) during the development cycle of the rice. The weed infestation began early from 45 DAT and the peak was

observed at 75 DAT with an average of 9.5 plants per meter square for T3 contrary to 5 and 5.25 plants per square meter respectively for T1 and T2 (see the curves in the Figure 3.2).
The extent of the weeds in 2011 was due to the fact that no weed management was practiced on the plots during the experiment. Weather conditions (rainfall, humidity and temperature were higher in 2011) also contributed to this emergence of those weeds. Weeds especially the graminoid compete more with cereals because of their similar growth behavior, rooting profile and nutrient requirements. Weeds absorb nutrients growing more efficiently than crop.
The histograms in the Figure 3.2 by tale show the number of rice plants infested by the yellow stem borer *(Scirpophaga incertulas)* in 2011. The higher the density of *E. pyramidalis* is raised on the plots, the more serious the borers attack the rice plants. The maximum density of *E. pyramidalis* on the T1 plot was 5plants/m^2 and the maximum average number of parasitized rice plants in these parcels is about 27. On the T2 plot there were 5.25plants/m^2 of *E. pyramidalis* and 33/m^2 infested rice plants. Additionally, on T3 plot there were 9.5plants/m^2 of *E. pyramidalis* and 60 plants/m^2 infested rice plants. The T3 treatments had the highest average weeds density (9.5plants/m^2) and the highest average infested rice plants (60).

Insect-plant interaction

Insect-plant interaction refers to the activities of two types of organisms: insects that seek out and utilize plants for food, shelter, and/or egg-laying sites, and the plants that provide those resources. The Figure 3.2 shows two kinds of relationships: (1) Link weeds (E. pyramidalis) / insects (S. incertulas), (2) Link weed density / the number of rice plant attacked.
Weeds can harbor pests and diseases which transfer to the crop [31]. The results showed that E. pyramidalis was the medium host plant of rice yellow stem borer Scirpophaga incertulas. This results confirms those phenomena [32]. This pyral whose first generation emerged from Echinochloa pyramidalis will lay its eggs on rice plants in favor of environmental conditions. The weeding of E. pyramidalis is particularly difficult because it germinates with rice plants and emerges in the same hill with the crop. Consequently the insects that E. pyramidalis harbors can easily transfer to the rice plants.

Nuisance Factor of Insects (*Scirpophaga incertulas*)

The nuisance of an insect on a plant is the amount of damage that the bug can cause on its host. In farming an insect may be classified as a pest if the damage it causes to a crop is sufficient to reduce the yield and/or quality of the 'harvested product' by an amount that is unacceptable to the farmer. With a rate of 14.81% of infested rice plants (**Ip**), the yellow borer *Scirpophaga incertulas* had caused an economic loss of P= 10.39% for the treatment T3. *Scirpophaga incertulas* had induced the highest rate of nuisance (C=0.7) to the treatment T3. On the other hand, the treatment T1 presented the lowest economic loss P=4.33% and the rate of nuisance (C=0.52) shown in Table 3.10.

Table 3.10 : Economic loss due to yellow bore (*Scirpophaga incertulas)*

Treatments	C	Ip (%)	P (%)
T1	0.52	8.25a	4.33a
T2	0.56	7.87a	4.37a
T3	0.70	14.81b	10.39b

In the column, averages followed by the common letter(s) are not significantly different at level of P≤5%.

The damage symptoms of *Scirpophaga incertulas* vary according to the stages of growth of the rice plants. During the very early stages of growth, the larva damaged the growing point in the terminal shoot. This condition is known as 'dead heart'. If the borers attack occurred at the flowering stage, the resulting panicles would become white and empty, known as the 'white head'. The empty paddies do not have any economic value.

Grain yield under controllable irrigation regime

The grain yield is the amount of grain harvested per unit area for a given time (Rabbinge, 1993). In agriculture, the crop yield is a measure of the grains or dry matter quantity in a particular area. It is usually expressed in kilograms per hectare (or metric tons per hectare). The Table 3.11 below points out the results of rice grain yield at 14% of humidity obtained in a field after drying. The lowest grain yield is observed in the control T1 plot (6.7T/ha) whereas the T3 plot showed the highest grain yield (7.56 T/ha). However, the treatments did not affect the rice ear length. The gap between the theoretical yield and the real or actual yield was higher on T1 (3.19 T/Ha) plot than the one under RCCI model treatments.
The resulting yield, obtained in a field injured by one or several pests, is defined as the actua1 yie1d (Rabbinge, 1993); it is the yield actually harvested in a farmer's field.Yie1d loss or damage represents the difference between the attainable and the actual yield, that is, the yield loss caused by pest injuries.

Table 3.11 : Grain yield under controllable irrigation regime

Treatments	Theoretical Yield (T/Ha)	Actual Yield (T/Ha)	Yield gap (T/Ha)	Ear length (cm)
T1	9.89a	6.7a	3.19	17.0
T2	9.25b	6.63a	2.62	17.5
T3	10.35c	7.56b	2.79	17.03

In the column, averages followed by the common letter(s) are not significantly different at level of P≤5%.

The yield gap between the theoretical yield and the real or actual yield was the result of several combined factors: (1) Yield loss due to weeds that can reach 79% for the density of 269 plants per square meter of weeds; (2) Yield loss due to insect attacks S. incertulas that accounts for 14.81% of rice plants causing an economic loss of P= 10.39% can reach 20% according to [34]; (3)Loss of yield due to poor agricultural practices.

4 Conclusion

This study assesses the environmental effect of Rain Catching and Controllable Irrigation on paddy field. The mechanism of RCCI model showed its ability to reduce the irrigation water supply by 36% with maximum use of rainfall, by reducing percolation and evapotranspiration the plots. Also, the RCCI model proved its involvement in environmental protection by improving the soil aeration through the development of rice root activities; the development of microorganisms and by reducing significantly the groundwater pollution and weakening erosion.

Pests in the paddy field were serious in 2011 than 2010. The weeds Echinochloa pyramidalis increased from 4plants/m2 to 9.5 plants/ m2 on RCCI compared with conventional irrigation model. The borer Scirpophaga incertulas attacks were earlier and sterner in 2011 and caused a huge economic loss P= 10.39%.

The RCCI treatment showed a performance in water use indices by: lowest irrigation quota (386.4mm), highest crop Water Use efficiency (18.06kg/mm) and lowest drainage amount (84.14mm). The RCCI had present the half of nitrogen lost (9.17kg/ha) of the conventional irrigation treatment (20.28kg/ha). The RCCI model also reduces at least half phosphorus losses by reducing the volume of drainage water from 150.25mm (T1) to 84.14mm (T3). Also, it had a higher actual rice grain yield (7.56 T/Ha) and the lowest yield gap (2.79T/Ha); thus, it was a beneficial treatment with less environmental pollution.

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