Saving water? Analysis of options for rice-based farms in Tamil Nadu, India

Kalimuthu Senthilkumar

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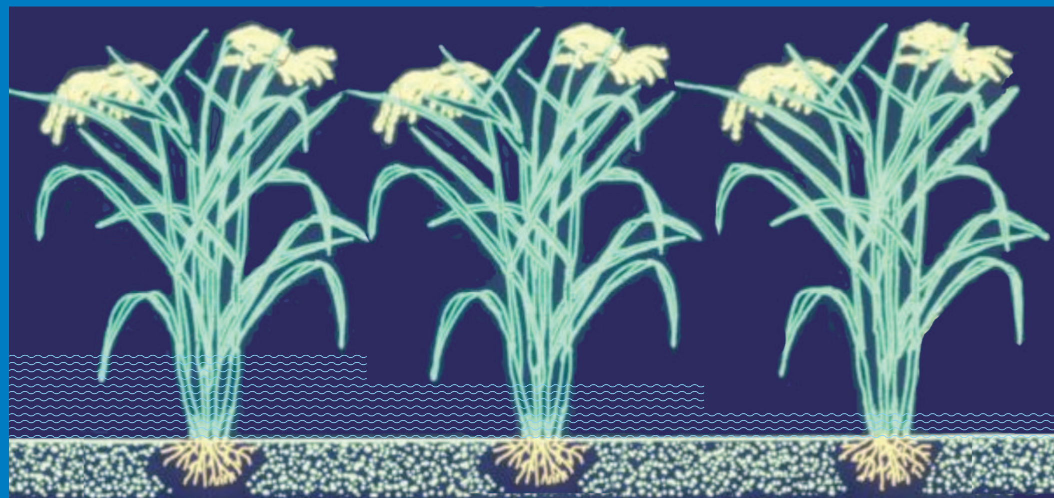

Kalimuthu Senthilkumar

Propositions

1. Farmers aim to maximize their economic output which conflicts with the best use of commonly available resources from the perspective of society at large (*This thesis*).

2. When the farmers are aware of a technology that satisfies their objectives, they will rapidly adopt it without a need for external support (*This thesis*).

3. Identifying an optimal solution for a 2 ha farm in a developing country is more complex than for a 100 ha Dutch farm.

4. Fragmentation of land indirectly will lead to an increase in farm size in India.

5. There is no absolute water shortage in the world for agriculture, but we lack good management of water resources.

6. Economic development and globalization has disfavoured the farming community in developing nations like India, compared with their role in earlier societies. (This proposition is derived from the Thirukkural, couplet 1033, written during the 1st millennium BC).

   "They live, who live to plough and eat;
   the rest behind them bow and eat"

7. Conflicts in the world arise due to resource scarcity; peace can be achieved by using the resources efficiently.

8. A similarity between Science and Religion: Both are products of human mind to improve human welfare but also lead to destruction.

Propositions belonging to the PhD thesis:

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Saving water?

Analysis of options for rice-based farms in Tamil Nadu, India

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Dedicated to the farmers of Tamil Nadu

Abstract

The looming water crisis and water-intensive nature of rice cultivation are driving the search for alternative management methods to increase water productivity in rice cultivation. Solely reducing water use in rice resulted in proportional reduction in yield, hence various management practices of rice cultivation have to change simultaneously to enhance water productivity, without reducing the productivity of other factors, primarily land (i.e. yield), labour and fertilizer. Experiments were conducted under on-station and on-farm conditions to compare rice production using modified methods of planting, irrigation, weeding, and nutrient management with conventional methods of cultivation. An yield advantage of up to 1.5 t ha^{-1} was achieved with a water-saving of 40% for the combination of modified methods over conventional methods. However, adoption by farmers remained limited due to the increased labour demand for modified planting, unwillingness of agricultural labourers to change practices, difficulties with modified nursery preparation and gender issues related to mechanical weeding. Potential for adoption of novel cultivation practices depends on the structure and functioning of the farm, hence four rice-based farm types were identified based on biophysical and socio-economic characteristics of the farms using principal component analysis. Opportunities exists in all four farm types to adopt one or more components of modified rice cultivation, but change in government policies are needed to improve adoption such as rules and regulations, pricing, institution building and infrastructure development, as well as training and education to farmers. An identical set of policy interventions cannot be applicable in all farm types since current resource use efficiencies and adaptability to changes differed substantially. Hence, we quantified current use efficiency of water, labour, nutrient and capital in all four farm types both at crop and farm level and qualitatively assessed the possible impact of different policy measures differentiated per farm type. A multi objective linear programming (MGLP) model was developed to explore quantitatively the impact of government policies introducing water pricing and water quota on adoption of modified rice cultivation including water-saving irrigation and related impact on farm profit. The combination of modifying rice cultivation and water pricing was effective in achieving both the objectives of farmers (i.e. maximizing income) and the society at large (i.e. increasing the use efficiency of water resources through inclusion of modified rice cultivation in the farming plan). The required degree of water pricing has to be kept low since higher prices lead to decrease in farm profit. Impact differed across farm types and affected poor resource endowed farmers most. Providing water quota can be an option to protect the livelihoods of poor resource endowed farmers. Apart from government water pricing and quota, policy instruments such as training and education in modified rice cultivation practices, development of irrigation infrastructure and organised cooperative management of

commonly available water resources could have impact on the adoption of modified rice cultivation but this remains to be clarified.

Keywords: Modified rice cultivation, Water-saving, Farm typology, Technology adoption, Policy interventions, Farmers livelihoods, Resource use efficiency and Linear programming.

Preface

I grew up among a farm family and during my school days, I used to farm with my parents during my holidays. Farming purely depended on rainfall with no irrigation facilities (dryland farming system in Ramanathapuram district, Tamil Nadu). Though I have many incidents to remember from our farming I would like to share three of those which are related to this research.

At the age of 12, while walking in the rice fields (semi-dry rice which was cultivated using only rainfall) with my mum, I felt my feet pressing on roots of rice. This scared me from continuing to walk but my mum would just go on. I stopped my mum and told her, “Mum, we are damaging the rice plants. See we are destroying the roots”. My mum replied, “Don’t worry, destroying rice roots a little bit will produce more tillers and more yield”. I did not understand how it was possible but this was proven through my on-station experiments on mechanical weeding with rice. The soil stirring and pruning of roots by mechanical weeding increased both tillering and yield.

I experienced the pain of water scarcity with farming. Chillies (*Capsicum annuum*) was the cash crop we used to cultivate. When there was no rain, we used to carry water in pots and irrigate individual plants by providing a cup of water precisely to the root zone. The other farmers in the village also did the same and continue to do so to date.

In case of water-scarcity in rice, especially in the latter period of the growing season such as flowering, we were not in a position to irrigate individual plants as we did for chillies. Instead the villagers organised social events to pray for rain. Sometimes the prayers did not reach the eternal power and the rice plants failed to flower. We harvested feed for cattle instead of food for us.

These memories were a great inspiration and motivation to conduct my research on saving water in rice-based farms in Tamil Nadu. The research was a quest to help rationalise water use in rice production. Hopefully the results will go a long way to help farmers use water more efficiently.

Contents

Chapter 1

Introduction

1. Preamble

The famous Tamil poet Thiruvalluvar wrote in his work the Thirukkural, a work of universal thoughts and truths about life; 'the book that never lies', the following two couplets on ‘farming’ and ‘the blessing of rain’:

They live, who live to plough and eat;
The rest behind them bow and eat
(Thirukkural, couplet 1033)

Water is life that comes from rain;
Sans rain our duties go in vain
(Thirukkural, couplet 20)

Thiruvalluvar wrote his Thirukkural somewhere during the 1st millennium BC, but his simple two-line poems, displaying the value and way of life, are still applicable nowadays. The above truths about farming and rain, can be confirmed: farmers are able to live freely and deserve respect, as they provide us with food; and our life in the world is impossible without rain/water. Although everyone may recognize the value and truth of both these Thirukkural couplets, they seem to have a more complex, conflicting and interrelated nature than one would expect. This is especially true today on the native soil of the poet, in Tamil Nadu, where water resources are not sufficient enough to meet the growing demands. As a consequence farmers are facing problems with the cultivation of their crops, especially rice.

2. Farming and farming community

About 65% of the population of the state of Tamil Nadu is engaged in agriculture for their livelihood, with rice as a major component of farming. Nearly 90% of the farmers are small holders have less than 2 ha of land and they are resource poor. The annual rainfall in this region is poor and highly erratic. The farmers and farming activity are vulnerable to water deficits as crop production can be seriously affected by unforeseen climatic variations. In this water deficit condition the awareness among the farmers to effectively utilise the available natural resources and conservation is still lacking. Most farmers prefer to over irrigate their crops, particularly if water for irrigation is available, in order to minimise the risks of crop failure. The irrigation water delivered through canals is utilised inefficiently by the lowland rice farmers at the head of the canal, which leads to reduced water supply to the tail-end farmers to cultivate crops. This creates an imbalance in water supply and water productivity in the irrigation scheme. Groundwater levels have fallen over the past two decades from some 5-10 meters below soil surface to over 60-100 meters (Public Works Department, 2004). The ground water potential has already over-exploited over nearly 45% of the total area of the state . As a result, the farmers' means to escape poverty is limited but they explore all options to ensure their livelihood. Strategies vary from incorporation of more profitable crops in the cropping system, to engagement in off-farm employment.

3. The state of Tamil Nadu

Tamil Nadu is situated in Southern India and the name came from the native speaking language "Tamil". It has a semi-arid climate with a mean annual rainfall of 959 mm. The mean maximum and minimum temperature in the plain are 33.8 and 22.4ºC. It has three distinctive seasons namely Kharif (June – September), Pishanam (October – January) and Summer (February – May). Pishanam is the monsoon season in which 70% of the annual rainfall is received. There are two main river basins – namely the Cauvery and the Thamirabarani river basins where rice cultivation is predominant. The proposed research was conducted in the Thamirabarani rice basin and some farm surveys were extended to the Cauvery river basin. The vital statistics of the state and the two districts Thirunelveli and Thoothukudi which come under the Thamirabarani river basin are presented in Table 1. Tamil Nadu has a total area of 130,058 km^2, and a population of 62 million (2001 Census). The literacy rate is 65% and the per capita annual income at current price is 709 US\$ y^{-1}.

Table 1. The biophysical and socio-economic characteristics of the study area.

Parameters	Tamil Nadu	Thamirabarani river basin	
		Tirunelveli District	Thoothukudi District
a) Biophysical characteristics			
Total geographical area (M. ha)	13	0.68	0.46
Agricultural area (%)	46	29	39
Agricultural area under irrigation (%)	56	70	26
Agricultural area under rice (%)	34	43	11
Average size of land holding (ha)	0.9	-	1.4
Land holding less than 2 ha (%)	90	-	81
Average min and max temperature (ºC)	22.4 – 33.8	22.5 – 30.5	24 – 35.8
Mean annual rainfall (mm)	959	815	656
b) Socio-economic characteristics			
Population (million)	62.4	2.8	1.6
Literacy rate (%)	65	68	72
Population under farming (%)	65	-	-
Per capita income at current price (US\$ y^{-1})*	709	-	-

*Exchange rate is INR 45 US\$$^{-1}$; Source: (Season and crop report, 2006; Statistical Handbook, 2006)

4. Farm production systems in Tamil Nadu

The farm production systems in Tamil Nadu are broadly classified into three groups: 1) Lowland farm production; 2) Irrigated dryland farm production; and 3) Dryland farm production. The above-mentioned classification of farm production systems is based largely on resource use and main income generating activities. The earlier studies on farm production systems did not consider the bio-physical and socio-economic conditions of the farming community in relation to adoption of new innovations. Detailed characterization of farms based on bio-physical and socio-economic conditions has not been done. The detailed description of the existing farm production systems are presented to give an overview of the farming conditions in Tamil Nadu.

Lowland farming is practiced where the water is available in plenty, the low-lying areas along streams, rivers and in the delta region. Flooding and waterlogging is common in the rainy season due to intensive rainfall. The main crops in this system are rice, banana and sugarcane. Most of the rice produced for the market comes from this system. Often the farmers have no other cropping options except rice because of waterlogging, though they are willing to grow other cash crops such as capsicum, cotton, turmeric, groundnut. Water release for irrigation is controlled by the water delivery systems as field to field irrigation is common with insufficient irrigation channels; hence the farmers cannot control the water. The farmers have the option of pumping ground water for their fields when water is not available in the canals, to complete their cropping cycle. In this system, the farm family and farm animals are clustered in villages. They visit their fields often to carry out the field operations.

In the irrigated dryland farm production system, the farmers have control over the irrigation water. The irrigation source is the ground water and stored water in the ponds or tanks. Farmers can grow any crop they choose taking into consideration the limitations on water availability and land suitability. Rice is cultivated mainly for home consumption and the other major crops are cotton, groundnut, maize, turmeric, vegetables and banana. Livestock are maintained within the farm, in presence of a farm house, otherwise kept at the homestead in the villages. In both irrigated lowland and irrigated dryland systems, electricity to pump the ground water is provided free of cost. The water from water delivery systems such as canal, tank in lowland farming system is also free of cost. However, all the farmers pay a common water tax and an initial electricity connection charge.

In the dryland farm production system, the only source of water for cropping is rainfall. Depending on the expected rainfall in the region the farmers will select their crops. The crops cultivated are groundnut, cotton, capsicum, millets and rainfed rice. Rice is cultivated only in the monsoon season, and mostly for home consumption. The livestock are mainly sheep and goats.

The integrated farming system is a mix of farm enterprises such as crop, livestock, aquaculture, agro-forestry and fruit crops to which the farm family allocates its resources in order to manage the existing environment for the attainment of family goals (Pandey et al., 1992). In Tamil Nadu, farmers have cultivated crops and reared animals for millennia, but there has been poor integration of these components because of problems of initial investment and labour requirements. A group of scientists in Tamil Nadu Agricultural University has been working on integrated farming systems (IFS) for the past decade and came up with fruitful results and presented many papers on the advantages of IFS over the conventional farming system. To enhance the productivity, economic returns and employment generation for family labour, integration of crop with fish + goat/poultry could be advocated rather than cultivating the crops alone under lowland farm production system. Better residue recycling is achieved through integration of crop with fish + poultry than with other systems (Jayanthi et al., 2002). Integrated farming systems provide an opportunity to increase economic yield per unit area per unit time by virtue of intensification of crop and allied enterprises (Jayanthi et al., 2002).

5. Water-saving in rice

Rice is not an aquatic species as it evolved from a semi-aquatic ancestor and does not necessarily need to grown under inundated conditions (Lafitte and Bennett, 2002). Inundated conditions in rice reduce weed pressure, act as a buffer when supply of water is low or unreliable, increase the availability of nutrients (De Datta and Patrick, 1986), helps in biological nitrogen fixation (Kundu and Ladha, 1995), ease animal traction for puddling and suppress soil-borne pathogens such as nematodes (George et al., 2002; Lafitte et al., 2002). Reducing the degree of flooding in rice may lead to reduced yields, primarily due to changes in crop physiology and increased weed infestation (De Datta, 1981; Bouman and Tuong, 2001; Warner et al., 2006). Therefore other agronomic practices must be adjusted simultaneously to prevent yield loss (Bindraban et al., 2006).

The System of Rice Intensification (SRI) is an approach introduced in Madagascar where several practices in rice cultivation were modified simultaneously which resulted in increased rice yields from 2 to 6 t ha¯1 on farmers fields in Madagascar (Stoop et al., 2002; Uphoff, 2002). However, SRI became controversial among scientists because miraculous yields of 15 – 23 t ha^{-1} were reported (Rafaralahy, 2002) which are much higher than the potential yield for rice (10 – 12 t ha^{-1}) (Thiyagarajan et al., 1993). Proponents supported the yield advantages achieved by SRI (7 – 15 t ha^{-1}) in infertile soils with greatly reduced rates of irrigation and without external inputs (Uphoff, 1999; Uphoff, 2001; Stoop et al., 2002; Stoop and Kassam, 2005). Opponents criticised SRI as non-science, UFOs (unconfirmed field observations) that have little potential for improving rice production (Dobermann, 2004; Sheehy et al., 2004; Sinclair and Cassman, 2004; Sheehy et al., 2005). SRI was difficult for most farmers to practice because the method requires significant additional labour input at a time of the year when liquidity is low and labour effort is already high (Moser and Barrett, 2003). The experiments and simulation studied conducted by the opponents resulted in no significant yield advantage with SRI and reported that the higher yields observed by the proponents are possibly due to measurement error (Sheehy et al., 2004; Sheehy et al., 2005). These controversies still continue in the recent papers of proponents (Uphoff et al., 2008) and opponents (Latif et al., 2005; McDonald et al., 2006). However, the research on SRI is continuing in many rice growing Asian countries and has yet to prove whether SRI is a feast or famine for the farming community (Surridge, 2004).

The recent development in rice cultivation in the state is the water-saving rice production. Some of the management practices of System of Rice Intensification (SRI) were adopted, while others were adapted to the local conditions, such as the use of fertilizers as organic manures are in short supply. With the total modification in the rice cultivation, there is a possibility to reduce the amount of irrigation water up to 50% by keeping the soil saturated rather than flooded without reduction in grain yield (Thiyagarajan et al., 2002). Typically, total water input in rice fields varies between 500 and 3000 mm depending on environmental conditions and the length of the growing period (Bouman and Tuong, 2001; Bouman et al., 2002).

The total available irrigated area in Tamil Nadu is 1.08 ha per capita as compared with 1.7 ha per capita for India as a whole. It is estimated that the water supply-demand gap for irrigated crops will be about 21 billion m^3 in 2025 (Palanisamy and Paramasivam, 2000). The domestic and industrial use of water, which claims 15% of the water resources, is expected to increase to 25% in 2025. Deterioration in the distribution structure of canal irrigation systems, overexploitation of ground water resources, and neglect of tank systems seriously reduce the availability of water for agriculture (Selvarajan, 2001). However, in recent times the government of Tamil Nadu implemented the tank de-silting project and continues to conserve rain water.

Water shortage in Tamil Nadu has resulted in a reduction of the irrigated area and in a shift towards less water-demanding cropping activities. Area, production and productivity of rice fluctuated due to the fluctuation in annual rainfall in the state (Figure. 1). The water shortage led the farmers to leave their land as fallow. For example, in 2002, the percentage of fallow land was 39% of the total cultivable area of Thirunelveli district which is situated in the Thamirabarani river basin. To sustain present food self-sufficiency and to meet future food requirements, India has to realise an annual growth in rice productivity of at least 3% (Thiyagarajan and Selvaraju, 2001). With the current rice cultivation practices, ever increasing cost of inputs and unstabilised income from the produce reaped, the net income of the farmers has decreased drastically, and this leads to non-adoption of new technologies for increasing the production (Rangasamy et al., 1995).

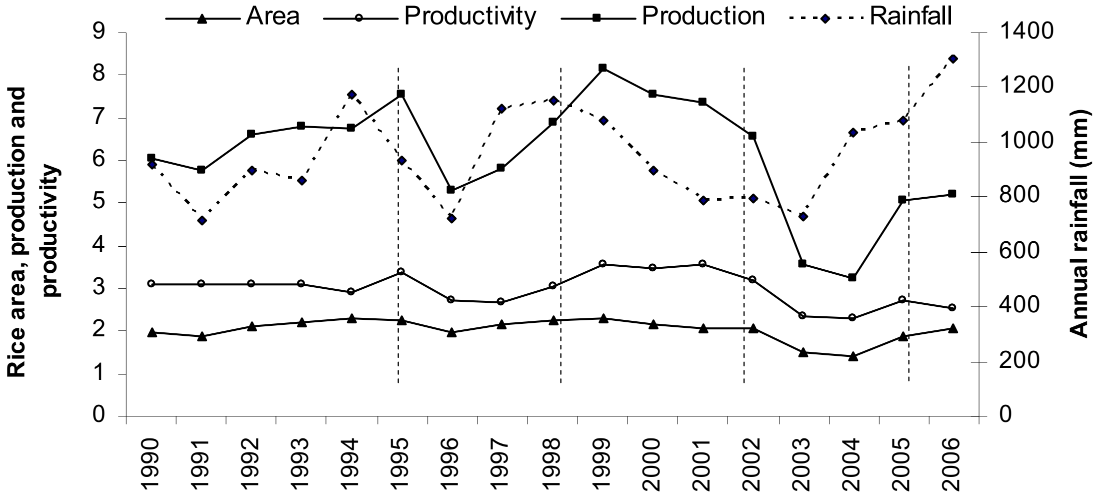

Figure 1. Area (million ha), production (million t y^{-1}) and productivity (t ha^{-1}) of rice based on the annual rainfall in the state of Tamil Nadu, India.

To successfully support the adoption process of water-saving rice practices by rice farmers in Tamil Nadu, a comprehensive understanding of the new technology and the factors affecting farmers' livelihoods is needed, whereby every farmer is likely to partially adopt or adapt the proposed practices depending on their own conditions. Hence, various rice production options should be explored, on how to conserve and effectively utilise the limited availability of land and water to attain maximum productivity and profitability for improving the livelihood of the smallholder farms of Tamil Nadu. These options can be explored by describing farm dynamics (biophysical) and by considering socio-economic factors (labour, income etc.) simultaneously in a farm model with an optimization procedure, such as multiple goal linear programming.

6. Objectives

The general objective of this study was to identify opportunities to enhance the productivity of rice-based farming systems by improving the efficiency of the scarcely-available water resources through the adoption of water-saving rice cultivation techniques. The specific objectives were:

- To evaluate water-saving rice cultivation technologies under on-station and on-farm conditions and to identify factors influencing the adoption strategies of the farmers;
- To understand the farm structure and functioning of the rice-based farming systems in order to assess the opportunities and constraints for farmers to adopt water-saving rice technologies;

- To estimate the current resource use efficiencies of the rice-based farming systems and to identify potential options to enhance the resource use efficiencies and farmers' livelihoods;
- To analyse the impact of water-saving technologies and policy instruments on adoption of water-efficient technologies and their impact on farmers' livelihoods.

7. Thesis outline and methodological approach

The thesis outline and the methodologies used in this study are presented in Figure 2. In Chapter 1 (this chapter), the state level water problems, past research on water-saving irrigation in rice and the potential options to save water in rice without penalty on yield are described. Two on-station experiments were conducted to study the effect of modifications in rice cultivation on water-saving and yield. To understand the experiences of the farmers, "modified rice cultivation" practices were compared with "conventional rice cultivation" practices through on-farm experiments. The on-farm experiments were conducted together with 200 rice farmers, each with 100 farmers in two rice-growing regions of the state; the Thamirabarani and Cauvery river basin. Farm surveys were conducted to assess the experience of the farmers with modified rice cultivation. The finding of these research components have been presented in Chapter 2 (Figure 2). To characterise the rice-based farms, a rapid initial farm survey was conducted in the Thamirabarani river basin in 100 farms. The farms were classified into four farm types based on the bio-physical and socio-economic conditions using Principal Component Analysis (PCA). The opportunities and constraints to adopt modified rice cultivation in the four different farm types were discussed (Chapter 3). After indentifying representative farms per farm type, a detailed farm survey was conducted for four consecutive seasons (16 months). Water, labour, nutrient and capital use efficiencies are quantified for each cropping activities and aggregated to the farm level resource use efficiencies in all farm types. The differences in resource use efficiencies due to the differences in resource endowments and characteristics of the farm are described and the potential effect of government poly instruments on enhancing resource use efficiencies and farmers' livelihoods are analysed qualitatively (Chapter 4). A static farm-level multi-objective linear programming model (MGLP) was developed using the General Algebraic Modeling System (GAMS) to study the impact of modified rice cultivation, government water pricing policies and in combination on adoption of water-saving irrigation and farm income quantitatively. The windows of opportunities available in the rice-based farms to enhance resource use efficiencies and farm income were explored (Chapter 5). In Chapter 6, the outcome of this study are discussed at a broader scale and the future research challenges to enhance resource use efficiencies and farmers' livelihoods in the state of Tamil Nadu are described.

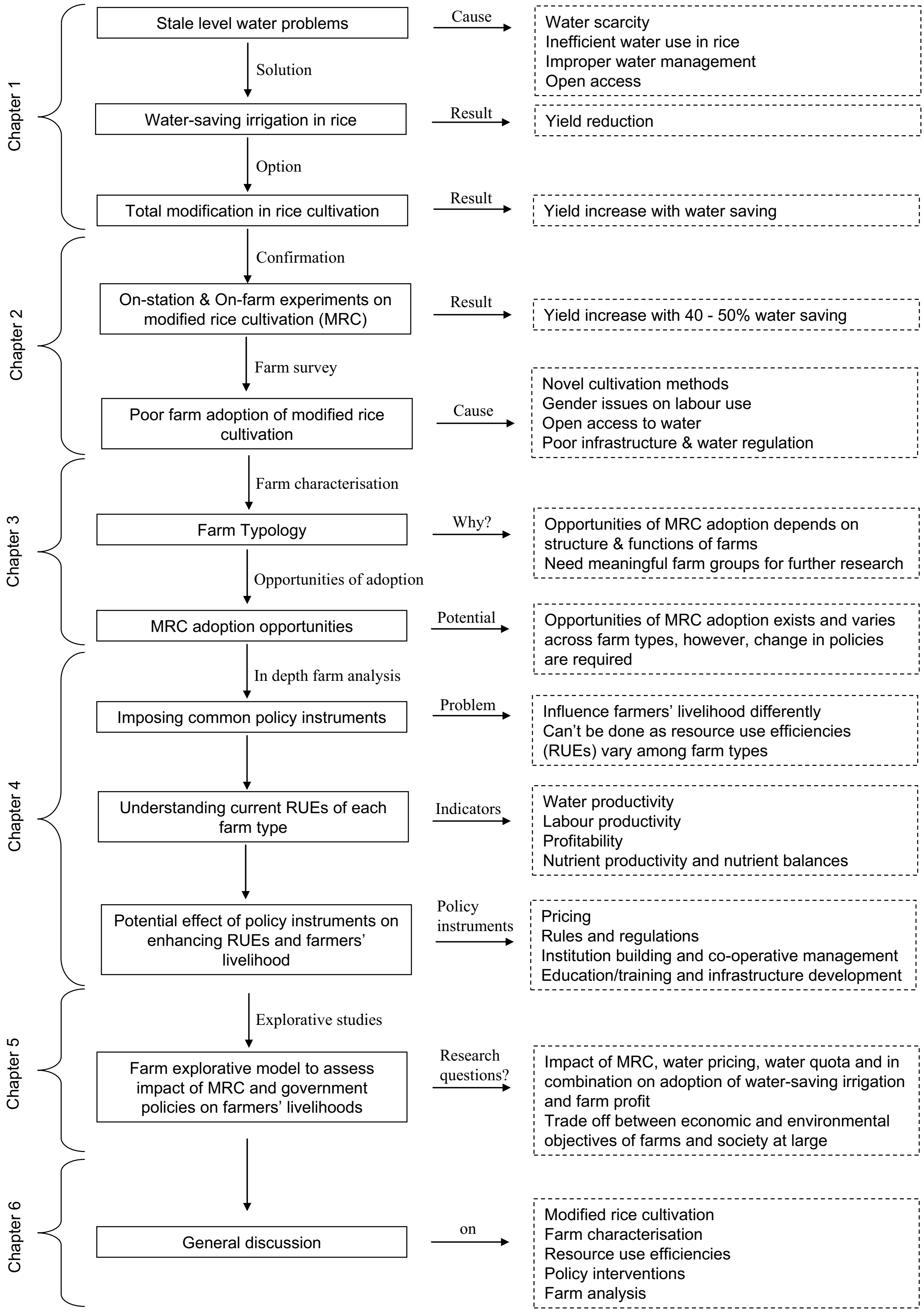

Figure 2. Thesis outline

Chapter 2

Modified rice cultivation in Tamil Nadu, India: Yield gains and farmers' (lack of) acceptance[†]

[†] Adapted from:
Senthilkumar, K., Bindraban, P.S., Thiyagarajan, T.M., de Ridder, N., Giller, K.E., 2008. Modified rice cultivation in Tamil Nadu, India: Yield gains and farmers' (lack of) acceptance. Agricultural Systems. 10.1016/j.agsy.2008.04.002.

Abstract

The looming water crisis and water-intensive nature of rice cultivation are driving the search for alternative management methods to increase water productivity in rice cultivation. Experiments were conducted under on-station and on-farm conditions to compare rice production using modified methods of irrigation, planting, weeding and nutrient management with conventional methods of cultivation. Farm surveys were used to evaluate adoption of modified rice cultivation method. On-station experiments showed that, a combination of water-saving irrigation, young seedling or direct seeding, mechanical weeding and green manure application increased the rice water productivity though the largest yields were obtained for a combination of conventional irrigation, young seedling or direct seeding, mechanical weeding and green manure application. On-farm experiments demonstrated a yield advantage of 1.5 t ha^{-1} for the modified method over conventional method. We found, however, that yield advantages were not the sole factor driving adoption. Associated changes required in management, including the increased labour demand for modified planting, unwillingness of agricultural labourers to change practices, difficulties with modified nursery preparation and the need to replace cheaper women's labour for hand weeding with more costly men's labour for mechanical weeding, all reduced the chance of adopting the modified rice cultivation method. Risks associated with water-saving irrigation, such as uncertainty about the timing and amount of water release for irrigation affect adoption adversely as well. There was no incentive for farmers to adopt water-saving irrigation as water from reservoirs and electricity for pumping well-water are both free of charge. To date farmers continue to experiment with the modified cultivation method on a small part of their farms, but are unlikely to adopt the modified method on a large-scale unless policies governing water management are changed.

Keywords: Modified rice cultivation; On-farm testing; Farm survey; Technology adoption

1. Introduction

Rice (*Oryza sativa* L.) is the predominant crop in Tamil Nadu, India. Its cultivation consumes 70% of the water available for agriculture; similar to many other regions of south and south-east Asia. Water is an increasingly scarce resource – the gap between water supply and water demand for irrigated crops in Tamil Nadu is projected to reach 21,000 million m^3 by 2025 (Palanisamy and Paramasivam, 2000). The area sown with rice declined at an average rate of about 5000 ha yr^{-1} over the past two decades, with a shift towards cultivation of less water-demanding crops. The perceived water scarcity is experienced at the state level as only 56% of the agricultural area has access to irrigation (Season and Crop Report, 2006). The irrigation water is used inefficiently in lowland rice cultivation, whilst farms that do not have access to irrigation water experience water scarcity. When the monsoon fails, lowland rice also faces water scarcity leading to crop failure or farmers fail to plant their paddy. Though rice yields have increased on average by 82 kg ha^{-1} yr^{-1} over the past 15 years (Thiyagarajan et al., 2000), there is a need to economize on water use in rice production.

In the late 1990s, 65% of the population of Tamil Nadu was engaged in agriculture and nearly 90% of the farmers cultivated less than 2 ha. The number of smallholder farmers increased from 4.2 million in the 1970s to 7.4 million in the late 1990s with increasing fragmentation of land (State Planning Commission, 2004). These facts emphasize the need to improve agricultural productivity for the millions of resource poor farmers.

Reducing the degree of flooding in rice may lead to reduced yields, primarily due to changes in crop physiology and increased weed infestation (De Datta, 1981; Bouman and Tuong, 2001; Warner et al., 2006). Although increased yield with alternative wetting and drying (AWD) has been reported (Zhang and Song, 1989), recent findings suggest that this is the exception rather than the rule (Belder et al., 2004; Cabangon et al., 2004; Tabbal et al., 2002). Bouman et al. (2006) reported AWD treatments resulted in a yield reduction in 92% of the experiments they reviewed, varying from just above 0% to 70% yield loss compared with the flooded treatments. Therefore, other agronomic practices must be adjusted simultaneously to prevent yield loss. The System of Rice Intensification (SRI) is an approach introduced in Madagascar where several practices in rice cultivation were modified simultaneously (Stoop et al., 2002). The traditional flooding at 5 cm depth was replaced with water-saving irrigation of a thin film of water during vegetative growth; younger seedlings were transplanted at a reduced plant density; hand weeding was replaced by regular mechanical weeding to suppress the profuse growth of weeds when the soil is not flooded; and application of mineral fertilizers was replaced with large quantities of organic manure (Uphoff, 2001, 2002; Stoop et al., 2002). Introduction of these practices was reported to increased rice yields from 2 to 6 t ha^{-1} on farmers' fields in Madagascar (Uphoff, 2002, 2007).

SRI, however, became controversial among scientists because miraculous yields of 15 – 23 t ha^{-1} were reported (Rafaralahy, 2002). Proponents of SRI claimed that higher yields of 7 – 15 t ha^{-1} were achievable in soils with low inherent fertility, with greatly reduced rates of irrigation and without external inputs (Stoop et al., 2002; Uphoff, 2002; Stoop and Kassam, 2005). Others criticized SRI because of the lack of experimental evidence (Sinclair and Cassman, 2004; Sheehy et al., 2005). Doberman (2004) stated that SRI had little potential to improve rice production in intensive irrigated systems on favourable soils where yields are already high.

In response to the widely-perceived need to increase the efficiency of water use, a research programme was established in Southern India to explore alternative methods for rice production. Some of the management practices of SRI were adopted, while others were adapted to the local conditions, such as the use of fertilizers as organic manures are in short supply. On-station experiments were conducted from 2001 to 2003 yielding favourable results. In 2004, with further adjustments, adapted management practices for rice cultivation were tested in 100 on-farm trials in each two main river basins of Tamil Nadu, the Thamirabarani and the Cauvery. In 2004, a farm survey was carried out to assess both technical and social aspects of rice cultivation because effective innovations comprise both technical devices, methods and practices, and new social arrangements and practices (Hounkonnou et al., 2006). In 2006, a second farm survey evaluated the experience of farmers with the modified cultivation method.

This chapter describes: 1) on-station experiments on modified management practices for rice production; 2) the experiences of farmers in testing and adopting these practices; and 3) factors that influenced the success of introducing this new approach to rice production.

2. Materials and methods

2.1. On-station experiments

On-station experiments were conducted at Tamil Nadu Agricultural University, Coimbatore (11°N 77°E; 427 m above sea level). The experimental site had clay-loam soil with a pH of 8.3, EC of 0.54 dS m^{-1}, organic carbon content of 8.2 g kg^{-1}, available N ($KMnO_4$-N) of 0.11 g kg^{-1}, Olsen-P of 0.02 g kg^{-1}, and available K (NH_4OAc-K) of 0.35 g kg^{-1}. The depth of soil sampled was 15 cm.

Experiments 1 and 2 were carried out during the wet season from September 2001 to January 2002 with rice hybrid CORH2 and during the dry season from February to June 2002 with rice hybrid ADTRH1, respectively. Four management factors (see Table 1 for treatment details) were implemented as treatments in a split-plot design with four replicate blocks. The main plot treatments were planting method and irrigation application with sub-plot treatments of weed and nutrient management. Gross plot size; i.e. total plot area consisted of net plot area and sampling area used for destructive plant sampling, for both experiments was 26.4 m^2 and the net plot size; i.e. plot area used for final yield estimation, was 13.5 and 13 m^2 for Experiments 1 and 2, respectively. Square planting of 20 x 20 cm was used in all treatments to permit the criss-cross use of a mechanical weeder. Irrigation water entering each plot was measured using a Parshall flume from transplanting onwards. Rainfall during the growing season was monitored. Water productivity was calculated by dividing grain yield by the water applied through irrigation plus rainfall, expressed in kg grain m^{-3} water (Van Dam et al., 2006), though it can be expressed in different ways (Tuong et al., 2005; Tsubo et al., 2006; Bouman et al., 2007).

Table 1. Crop management practices tested in Experiment 1 using rice hybrid CORH2 (September 2001- January 2002, wet season) and Experiment 2 using rice hybrid ADTRH1 (February - June 2002, dry season).

Management factors	Conventional method	Modified method
Planting (P)	P_1: 24 day old seedlings transplanted from conventional nursery, single seedling $hill^{-1}$	P_2: 14 day old seedlings transplanted from dapog[1] nursery for Experiment 1 and in Experiment 2 direct seeding 2 – 3 seeds manually sown but later thinned to a single seedling $hill^{-1}$
Irrigation (I)	I_1: Irrigation to 5 cm depth one day after disappearance of surface water	I_2: Water-saving irrigation after crop establishment (irrigating to 2 cm depth after surface crack development). Experiment 1, water-saving irrigation up to flowering, followed by conventional irrigation during grain filling. Experiment 2, water-saving irrigation till maturity.
Weed management (W)	W_1: In Experiment 1, weeds removed by manual weeding (three times). In Experiment 2, pre-emergence application with herbicide Butachlor followed by manual weeding (two times)	W_2: Weeds mechanically incorporated with a mechanical weeder, criss-cross used five times during the growing season
Nutrient management (N)	N_1: Recommended amount of N (150 kg ha^{-1}), P (26 kg ha^{-1}), K (75 kg ha^{-1}) and Zn (10 kg ha^{-1}) applied in split doses	N_2: The same as conventional plus green manure; *Sesbania aculeata* (fresh weight 6.25 t ha^{-1} which added 58:6:49 kg of N:P:K ha^{-1})

[1]Dapog: this nursery method was developed in the Philippines, where seedlings are raised on a surface, like a polythene sheet, so they can be easily transported to the field and transplanted at a young age.

Plant samples were collected at active tillering, panicle initiation, flowering and harvest stages of crop growth. Five hills from each plot were randomly selected for analysis. After counting the number of total and productive tillers, the samples were sun dried for 2 – 3 days and then oven dried for a minimum of 8 hours at 70°C to constant weight to obtain total dry weight. Underground crop parameters were observed in both experiments by measuring the fresh root length (cm), root volume (cm^3 $hill^{-1}$) through water replaced by immersing roots and, root dry weight (kg ha^{-1}) by oven drying as for the total dry weight estimation. Grain yields were estimated by harvesting all the plants in the net plot area of each plot and expressed in kg ha^{-1} at 14% moisture content. Statistical analysis was conducted by ANOVA using the split-plot design using GENSTAT (Payne et al., 2002).

2.2. On-farm experiments

The results of the on-station experiments were considered sufficiently encouraging for the Government of Tamil Nadu to support Adaptive Research Trials (ART) together with 200 rice farmers during 2003–2004, with 100 farmers in each of the two major rice-growing areas of the state; the Thamirabarani river basin and the Cauvery river basin.

Farmers were informed about the modified rice cultivation method through field demonstrations and discussions prior to initiating the ARTs. Each ART compared modified rice cultivation method with conventional rice cultivation method, each performed on 1000 m^2 without replication. The components of the modified rice cultivation method were as follows. Seedlings of 14–15 days old from dapog nursery beds (a nursery method developed in the Philippines, where seedlings are raised on a surface, like a polythene sheet, so they can be easily transported to the field and transplanted at a young age) were transplanted, at one seedling per hill spaced at 20 x 20 cm. Mechanical weeding was carried out at 10-day intervals up to 40–45 days after planting starting 10 days after transplanting. A rotary weeder (i.e. a hand operated, light rotary hoe containing two simple rotating serrated blades) was used in the Thamirabarani river basin. A cono weeder (i.e. a hand operated, heavy implement with two serrated cones to stir the soil and incorporate the weeds) was used in the Cauvery river basin. The irrigation regime aimed to keep a water layer of 2 cm up to panicle initiation by irrigating when small cracks appeared on the soil surface, generally within 2–3 days after disappearance of the water layer. After panicle initiation, plots were irrigated immediately after disappearance of the standing water. The components of the conventional rice cultivation method were as follows. Seedlings of 24–35 days old from lowland nursery beds were transplanted in clumps of seedlings per hill with a population of around 50 hills m^{-2}. Weeds were removed by manual hand weeding twice, at around 20 and 40 days after transplanting. The conventional practice of irrigation to 5 cm depth one day after disappearance of surface water was followed throughout the crop period. The amounts of fertilizer applied were equal in both conventional and modified treatment plots. These on-farm ART trials were conducted under the supervision of research staff with special attention to seedbed preparation, transplanting and use of the mechanical weeder. Rotary/cono weeders were provided free of charge to all participating farmers. Grain yields at 14% moisture were recorded by collecting all panicles from five randomly selected areas of 1 m^2, totaling 5 m^2 from both the modified and conventional cultivation plots. Cultivation costs for both methods were collected by the research staff periodically. Not all the 200 farmers who participated in the ARTs, implemented all the components of the modified rice cultivation method. The problems occurred in execution of the treatments were: 1) farmers who did not maintain a modified nursery used a conventional nursery to provide seedlings for modified planting; and 2) fields in cascade system of irrigation cannot practice water-saving irrigation and they continued with conventional irrigation in the modified rice cultivation treatment. In the case of the Thamirabarani basin, only 36 farmers had adopted all the components. The benefit:cost ratio was calculated on the basis of data from these 36 farmers who had adopted all the recommended components of the modified rice cultivation system. The hiring costs and wage rates used for calculating benefit:cost ratio were as follows: cost of hiring a tractor = US$ 3.3 h^{-1}; cost of hiring a span of bullocks = US$ 4.4 h^{-1}; official wage rate for both men and womens' labour = US$ 0.9 labour-day^{-1}; actual wage rate for men = US$ 1.8 labour-day^{-1} and for women = US$ 0.9 labour-day^{-1}. The currency conversion factor used was 1 US$ = INR 45. No cost estimates were made in the Cauvery river basin.

2.3. Farm surveys

Two farm surveys were conducted to understand the factors that influenced adoption or disadoption of the technologies by farmers. The first survey was conducted from August to October 2004 in the Thamirabarani river basin to obtain a general description of the current situation of rice cultivation in both technical and social terms. In total 25 farmers were interviewed using a comprehensive questionnaire on the newly-introduced modified rice cultivation and problems associated with the limited and irregular availability of irrigation water. Among the 25 farmers surveyed, 18 farmers participated in the adaptive research trials and the remaining seven farmers were selected at random from those not participating in the trials.

The second, more extensive farm survey was conducted during June–September 2006. Of the 100 farmers in the ARTs in each river basin, one in every two farmers in the Thamirabarani and one in four in the Cauvery were interviewed. The survey aimed to understand farmers' perspectives on factors internal and external to their farms which influenced their adoption of the new technologies, and to identify the issues that need to be considered in the future for designing new options for improving the livelihood of the resource poor farming community. Farmers were given a total of 50 marks per set of internal and external factors previously identified by the researchers. The farmers could allocate these 50 marks to factors that affect their decision in adopting the new technology, following the procedure by Galpin et al. (2000). To assess farmers' experience in testing the modified rice cultivation method they were asked a series of questions relating to the soundness or difficulties in practicing modified method. In addition, farmers' spontaneous responses were documented on the problems they had experienced in practicing modified rice cultivation and their suggestions to improve the technology. The questionnaire was prepared in Tamil for ease of communication. Farmers were asked to estimate the grain yields at harvest (approximately 20% moisture content), from their own experience in ARTs and in their own subsequent trials, with both modified and conventional methods by indicating the number of bags they harvested for a given area and the average weight of the bags. The grain yields were converted to kg ha^{-1} at 14% moisture content.

3. Results and discussion

3.1. On-station experiments

3.1.1. Grain yield and dry matter production in Experiments 1 and 2

Grain yields varied between 5.1 and 7.6 t ha^{-1} in Experiment 1 (Table 2a) and between 5.7 and 6.9 t ha^{-1} in Experiment 2 (Table 2b). In both experiments, the largest yields were obtained for the combination of modified planting, conventional irrigation, mechanical weed control, and green manure application (Table 2).

In Experiment 1, overall grain yields with water-saving irrigation (6.4 t ha^{-1}) were similar to yields under conventional irrigation (6.5 t ha^{-1}; Table 2a) while on average 41% of the irrigation water was saved (Table 3). Practicing water-saving irrigation from transplanting to flowering, with maintenance of a thin layer of standing water during the post-flowering stage did not lead to reduced rice grain yields, which averaged more than 6 t ha^{-1} with all irrigation treatments (cf. Table 2a). Saving on irrigation water for rice production with no effect on yields has been reported by others: Bindraban et al. (2006) reported water savings up to 50% without penalty on yield for a range of experimental conditions. Sandhu et al. (1980) and Li et al. (2005) found no adverse effects on rice yields with intermittent irrigation at 1–5 days after disappearance of standing water which saved 25–50% water compared with continuous submergence. Purushothaman and Jeyaraman (1992) observed similar yields with partial submergence of rice fields at critical stages of growth compared with continuous submergence. In Experiment 2, yields with water-saving irrigation were significantly reduced to 6.2 t ha^{-1} compared with 6.5 t ha^{-1} for conventional irrigation (Table 2b). This yield reduction may have been due to the continuation of water-saving irrigation up to maturity, but 50% of the irrigation water was saved at the expense of 0.3 t ha^{-1} of grain yield.

The saving of 41% and 50% of the water with water-saving irrigation in the on-station experiments needs further scrutiny as we did not measure the depth of ground water table in the experimental field. Extremely shallow water tables of 10–40 cm reduce the

Table 2. Grain yield (t ha^{-1}) under four conventional and modified management practices in on-station experiments (Experiments 1 and 2)

a) Grain yield (t ha^{-1}) in Experiment 1 using rice hybrid CORH2 in wet season (2001–2002)

		Conventional planting (P_1)		Modified planting (P_2)		Mean
		Conventional irrigation (I_1)	Water-saving irrigation (I_2)	Conventional irrigation (I_1)	Water-saving irrigation (I_2)	
Conventional	N_1^a	6.2	6.2	6.8	6.3	6.4
weeding (W_1)	N_2^b	6.0	6.2	5.9	5.1	5.8
Mechanical	N_1^a	6.0	6.9	6.8	6.7	6.6
weeding (W_2)	N_2^b	6.3	6.4	7.6	7.1	6.9
Mean		6.1	6.4	6.8	6.3	

Comparison of means for P, I, W, N

	Conventional practice	Modified practice
Planting (P)	6.3	6.5
Irrigation (I)	6.5	6.4
Weeding (W)	6.1	6.7
Nutrients (N)	6.5	6.3

SED of means ($P< 0.05$)

Grain yield as influenced by P x W x N interaction

	W_1N_1	W_1N_2	W_2N_1	W_2N_2
P_1	6.2	6.1	6.5	6.4
P_2	6.6	5.5	6.8	7.4

SED for same levels of P, P.W, P.N=0.26; for same levels of W.N=0.39; NS=not significant

Main factors	SED (0.05)	Interactions	SED (0.05)	Interactions	SED (0.05)
Planting (P)	NS	P.I	NS	I.N	NS
Irrigation (I)	NS	P.W	0.37	P.I.W	NS
Weeding (W)	0.15	P.N	NS	P.I.N	NS
Nutrients (N)	NS	I.W	NS	P.W.N	0.42

b) Grain yield (t ha^{-1}) in Experiment 2 using rice hybrid ADTRH1 in dry season (2002)

		Conventional planting (P_1)		Modified planting (P_2)		Mean
		Conventional irrigation (I_1)	Water-saving irrigation (I_2)	Conventional irrigation (I_1)	Water-saving irrigation (I_2)	
Conventional	N_1^a	6.0	5.7	6.7	6.4	6.2
weeding (W_1)	N_2^b	6.3	5.8	6.6	6.4	6.3
Mechanical	N_1^a	6.2	6.0	6.9	6.4	6.4
weeding (W_2)	N_2^b	6.3	6.1	6.9	6.6	6.5
Mean		6.2	5.9	6.8	6.4	

Comparison of means for P, I, W, N

	Conventional practice	Modified practice
Planting (P)	6.1	6.6
Irrigation (I)	6.5	6.2
Weeding (W)	6.2	6.4
Nutrients (N)	6.3	6.4

SED of means ($P< 0.05$); NS = not significant

Main factors	SED (0.05)	Interactions	SED (0.05)	Interactions	SED (0.05)
Planting (P)	0.13	P.I	NS	I.N	NS
Irrigation (I)	0.09	P.W	NS	P.I.W	NS
Weeding (W)	0.07	P.N	NS	P.I.N	NS
Nutrients (N)	NS	I.W	NS	P.W.N	NS

For further explanation see Table 1. $^aN_1$ = Recommended amount of N (150 kg ha^{-1}), P_2O_5 (60 kg ha^{-1}), K_2O (90 kg ha^{-1}) and Zn (25 kg ha^{-1}) applied in splits. $^bN_2 = N_1$+fresh green manure @ 6.25 t ha^{-1}.

required water inputs by 15–30% without a significant impact on yield (Cabangon et al., 2004; Belder et al., 2004; Bouman et al., 2006). However, given the rapid reductions in water tables experienced in many parts of India (Seckler et al., 1999) with increasing shortages of drinking water in urban areas, there is a strong imperative for more efficient use of the available water. Dry matter production during the growing season followed a similar pattern for all irrigation treatments in both experiments except at harvest in Experiment 2 (data not presented).

The highest water productivity was obtained for conventional planting and water-saving irrigation in both Experiment 1 (0.73 kg m^{-3}) and Experiment 2 (0.87 kg m^{-3}). In these treatments, water productivity increased by 84% and 96%, respectively, compared with conventional irrigation (Table 3). The greater water saving in Experiment 2 compared with Experiment 1 was due to the continuation of water-saving irrigation up to maturity. The prolonged growing period after transplanting with younger seedlings or direct seeding in the modified planting method reduces however the amount of water saved when compared with the conventional planting method.

Table 3**.** Water productivity and water saving achieved in Experiments 1 and 2 (see Tables 1 and 2 for explanation of Experiments 1 and 2)

Particulars		Water used (10^3 x m^3 ha^{-1})			% water saved	Grain yield (t ha^{-1})	Water productivity (kg grain m^{-3})
		Irrigation	Rainfall	Total			
Experiment 1							
Conventional planting	Conventional irrigation	11.85	3.56	15.41	-	6.1	0.40
	Water-saving irrigation	5.21	3.56	8.77	43	6.4	0.73
Modified planting	Conventional irrigation	13.35	3.56	16.91	-	6.8	0.40
	Water-saving irrigation	6.70	3.56	10.26	39	6.3	0.61
Experiment 2							
Conventional planting	Conventional irrigation	13.41	0.56	13.97	-	6.2	0.44
	Water-saving irrigation	6.21	0.56	6.77	52	5.9	0.87
Modified planting	Conventional irrigation	16.63	0.56	17.19	-	6.8	0.39
	Water-saving irrigation	8.42	0.56	8.98	48	6.4	0.72

The use of young seedlings in Experiment 1 gave no significant change in grain yield (6.5 t ha^{-1} vs. 6.3 t ha^{-1}), comparable to findings by Latif et al. (2005). In Experiment 2, direct seeding resulted in a small, but significant increase in grain yield compared with conventional planting (6.6 t ha^{-1} vs. 6.1 t ha^{-1}), confirming earlier observations (Patel et al., 1983; Uphoff, 2001). Larger amounts of total dry matter were produced with modified planting method in both experiments (data not presented).

Grain yield was increased significantly by mechanical weeding: in Experiment 1 by 10% or 0.7 t ha^{-1} (Table 2a) and by 3% or 0.2 t ha^{-1} in Experiment 2 (Table 2b). Beneficial effects of mechanical weeding on rice yields have been attributed to improved aeration of the soil and effects due to incorporation of the weed biomass (Uphoff, 2001; Stoop et al., 2002), however, the effects of mechanical weeding need to be studied in detail. Differences in dry matter accumulation between the weed management treatments occurred primarily after flowering (data not presented). In neither experiment did the additional application of green manure affect yield. Modifications in irrigation, planting and weeding methods as introduced in the modified production method, however, did increase yields. The average yield for the conventional method was 6.1 t ha^{-1} in both the experiments. On average, introduction of any of these modified method gave 0.1 t ha^{-1} additional yield. In any combination of two modified methods, the yield advantage increased to 0.4 t ha^{-1}, and a combination of three modified methods gave yield advantages of 0.6 t ha^{-1}. Similar yield advantages for the introduction of an increased number of modifications were reported by Uphoff (2001).

On-station experimental results suggested that the combination of modified production methods rather than individual effects had a greater impact on yield. The combination of young seedlings or direct seeding, mechanical weeding, green manure application and conventional irrigation gave the largest yields in both seasons (7.6 and 6.9 t ha^{-1} in Experiments 1 and 2, respectively) under controlled experimental conditions (Table 2). The increased yield was attributed to a larger number of productive tillers found with the modified rice cultivation, largely due to the modified planting method (Figure. 1).

3.1.2. Grain yield and associated crop characteristics

Modified planting resulted in a significantly larger tiller density compared with conventional planting during the entire growth period in both experiments (Figure. 1). The number of productive tillers for the modified planting (287 m^{-2} in Experiment 1 and 400 m^{-2} in Experiment 2) was significantly larger than with conventional planting (243 m^{-2} in Experiment 1 and 328 m^{-2} in Experiment 2). This increase in productive tiller count was reflected in a significant yield increase only in Experiment 2 (Table 2a). There was no significant difference in total and productive tiller count for the irrigation and nutrient management treatments in either of the experiments (data not presented). Mechanical weeding gave an increased total number of tillers (Figure.1) at harvest in both experiments, but the number of productive tillers was significantly larger only in Experiment 1; 252 and 277 m^{-2} for conventional and mechanical weeding, respectively.

Greater root dry weight was recorded with modified planting (1.14 and 2.13 t ha^{-1} in Experiment 1; 0.74 and 1.54 t ha^{-1} in Experiment 2) compared with conventional planting (0.94 and 1.72 t ha^{-1} in Experiment 1; 0.7 and 1.45 t ha^{-1} in Experiment 2) at the crucial stages of crop growth such as panicle initiation and flowering stages, respectively, in both experiments. The root length (cm) and root volume (cm^3 hill^{-1}) were significantly increased by mechanical weeding at panicle initiation and flowering stages in both experiments (Nisha, 2002).

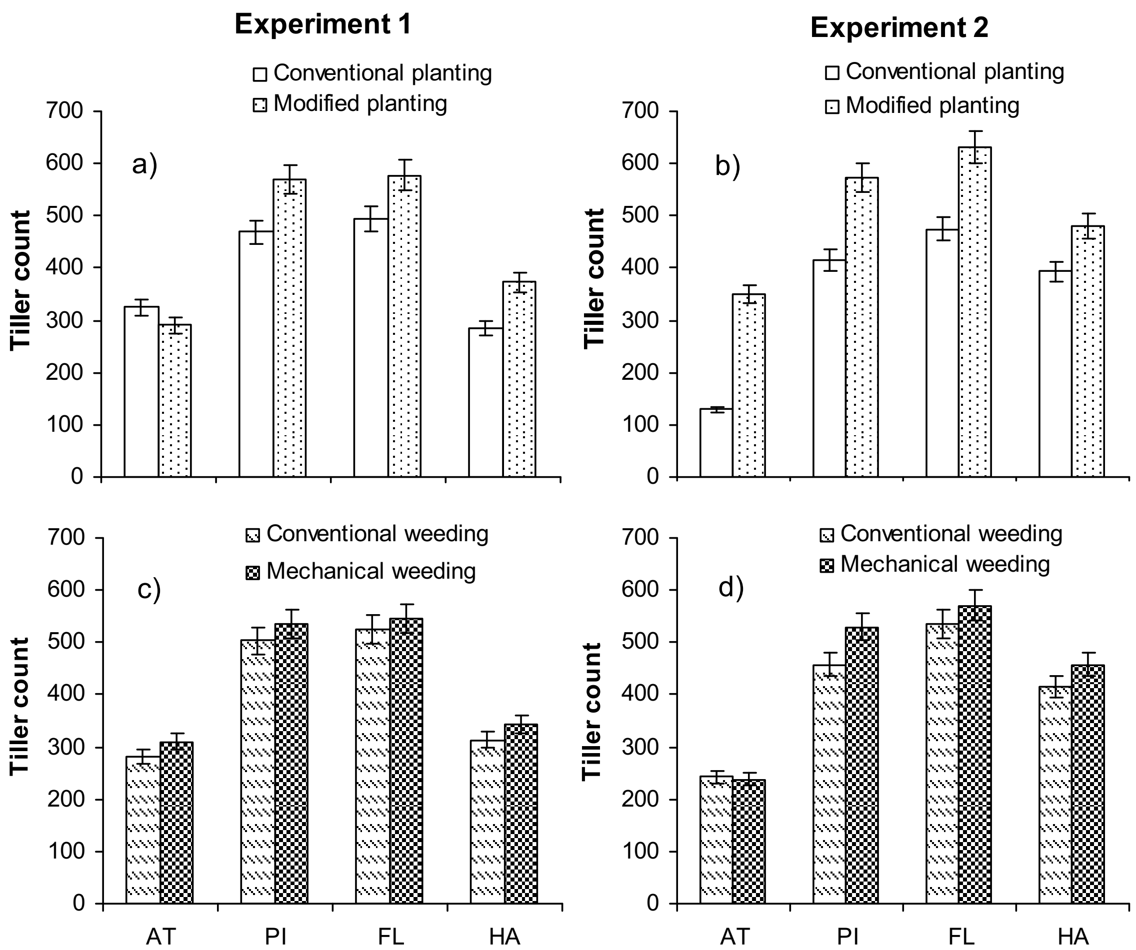

Figure 1. Total tiller density (number m^{-2}) in Experiment 1 (a, c) and Experiment 2 (b, d) influenced by planting (a, b) and weeding (c, d) in conventional and modified methods. The number of days after sowing (DAS) on which the sampling was done are as follows for conventional and modified treatments, and Experiment 1 and Experiment 2, respectively. (AT = Active tillering; 50, 36 and 42, 19 DAS, PI = Panicle initiation; 70, 56 and 60, 55 DAS, FL = Flowering; 95, 82 and 84, 81 DAS, HA = Harvesting; 131, 118 and 114, 113 DAS).

3.2. On-farm experiments

Grain yields in farmers' fields with modified rice cultivation in the Thamirabarani basin ranged from 4.2 to 10.7 t ha^{-1} (mean yield 7.2 t ha^{-1}; SD 1.4) and with conventional rice cultivation from 3.9 to 8.7 t ha^{-1} (mean yield 5.7 t ha^{-1}; SD 1.1). The overall yield advantage with the modified rice cultivation method was 1.5 t ha^{-1}. In the Cauvery river basin, the grain yield under modified rice cultivation ranged from 4.1 to 7.9 t ha^{-1} (mean yield 6 t ha^{-1}; SD 0.9) and for the conventional rice cultivation from 2.7 to 6.6 t ha^{-1} (mean yield 4.6 t ha^{-1}; SD 0.9). This gave an overall yield advantage of 1.4 t ha^{-1} for the modified rice cultivation method. A remarkable feature of the results was the consistency of the responses: in all farms the modified production method gave the same or better yield than the conventional method (Figure. 2). The reasons underlying this consistent response are not clear. A possible explanation is that farmers paid more care and attention to the plots in which the modified rice cultivation method were tested, but we have no evidence to support this from our field assistants or from our frequent visits to the field.

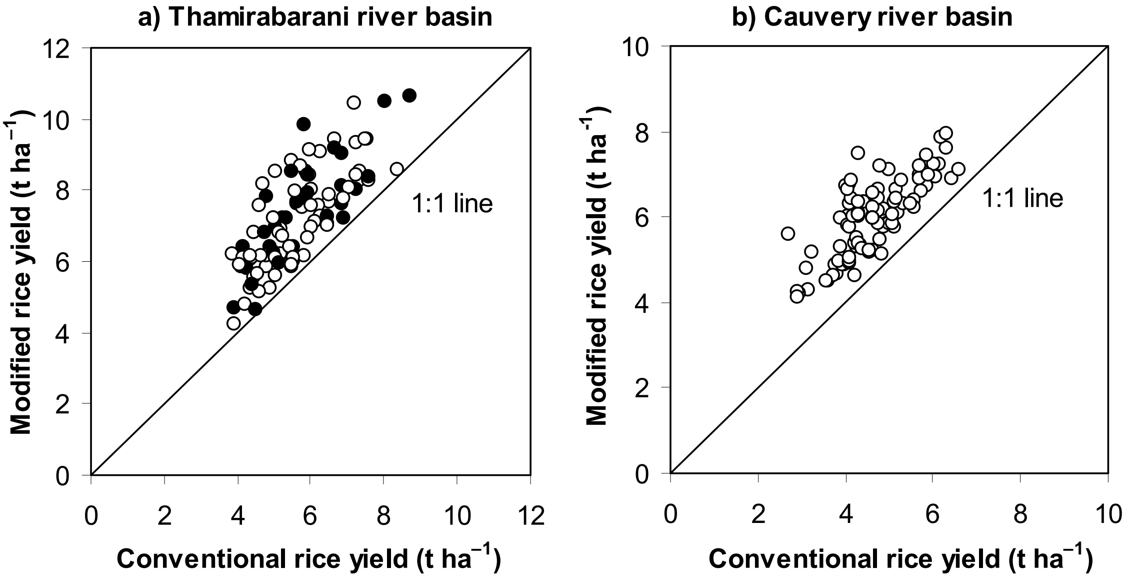

Figure 2. Yield advantage of modified rice cultivation method over conventional rice cultivation in the on-farm experiments in a) Thamirabarani (n = 100) and b) Cauvery (n = 100) river basin in 2004. Farmers in the Thamirabarani basin who adopted all the components of modified rice cultivation method (n = 36) are indicated by solid symbols.

An average overall cost saving under modified rice cultivation of 11%, including costs of all inputs, was found for the 36 ARTs in which the costs were documented in the Thamirabarani river basin (Table 4). The cost reduction was achieved through savings in labour, seed and fertilizer for nursery preparation and mechanical weeding.

The seed requirement for dapog nursery was reduced to 7.5 kg ha^{-1} compared with 60 kg ha^{-1} for the conventional nursery. No organic or inorganic fertilizer was applied to the dapog nursery which further reduced the cost. The dapog nursery does not require tractor ploughing as it is established near the homestead in a small area of 100 m^{2} ha^{-1} as against 800 m^{2} ha^{-1} for a conventional nursery (Thiyagarajan et al., 2003). The mens' labour requirement was halved from 6 to 3 labour-days for the dapog nursery as

Table 4. Management activities including inputs and costs (expressed on a ha^{-1} basis) used in conventional (C) and modified (M) rice cultivation methods of the on-farm adaptive research trials (ART) in the Thamirabarani river basin; Estimates from 36 ARTs in which all components of modified rice cultivation were practiced

Activities	[1]Tractor (h)		[2]Bullock pair (h)		[3]Men Labour (labour-day)		[4]Women Labour (labour-day)		Cost of 1-4 for official labour wage rate in US$		Cost of 1-4 for actual labour wage rate in US$		Total cost for official labour wage including material inputs (seed, fertilizer) in US$		Total cost for actual labour wage including material inputs (seed, fertilizer) in US$	
	C	M	C	M	C	M	C	M	C	M	C	M	C	M	C	M
Nursery preparation	1	-	-	-	6	3	0.5	5.5	9	8	15	10	47	15	52	18
Main field preparation	7.5	7.5	2	2	12	12	-	-	45	45	55	55	45	45	55	55
Manure & Fertilizer	-	-	-	-	7	7	10	10	15	15	22	22	161	161	168	168
Transplanting	-	-	-	-	5	5	55	75	54	72	59	77	54	72	59	77
Weeding	-	-	-	-	-	38	80	-	72	34	72	68	72	34	72	68
Irrigation	-	-	-	-	7.5	6	-	-	7	5	14	11	7	5	14	11
Plant protection	-	-	-	-	2	2	2	2	4	4	5	5	15	15	17	17
Harvesting	1	1	-	-	12.5	12.5	75	75	82	82	93	93	82	82	93	93
Total	9.5	8.5	2	2	52	85.5	222.5	167.5	288	265	334	342	483	429	529	506

Table modified from (Thiyagarajan et al., 2003). For explanation of methods of cultivation (C and M), see text.

daily irrigation was not required. The watering for dapog nursery was done by women labourers using a watering can three times a day which increased the women's labour requirement. The overall cost for the dapog nursery was reduced from US$ 47 to US$ 15 for one ha of transplanted rice (Table 4).

The amount of labour required for weeding was reduced by half (Table 4) due to the use of the mechanical weeder. If labour costs were calculated based on the official labour wage rate of US$ 0.9 labour-day^{-1} for both men and women, the costs were 11% less for the modified method. Traditionally in Tamil Nadu, hand weeding of rice fields is done by women labourers whereas machines are used by men. Introduction of mechanical weeding led to a shift from the use of womens' labour for hand weeding to mens' labour for mechanical weeding with the modified rice cultivation. Taking this gender differentiation into account and the related actual differentiation in wages, i.e. US$ 1.8 labour-day^{-1} for men and US$ 0.9 labour-day^{-1} for women, the overall cost saving was reduced to 5% (Table 4).
The cost of transplanting was higher in modified rice cultivation as line planting leads to a higher labour requirement. This was due to the extra care needed to handle young seedlings and the time taken to plant with regular spacing to allow mechanical weeding (Table 4). The labour requirement for water-saving irrigation was less as the time required per irrigation and frequency of irrigation both are reduced compared with conventional irrigation. There was no difference in cost for field preparation, manure and fertilizer purchase and application, plant protection and harvesting (Table 4).

The average gross and net income through sale of grain and straw for the 36 farmers who had adopted all components of modified rice cultivation was US$ 954 and 448, respectively (average grain yield 8 t ha^{-1}; straw yield 11.7 t ha^{-1}) and US$ 724 and 195, respectively (average grain yield 6.1 t ha^{-1}; straw yield 9.1 t ha^{-1}) for conventional rice cultivation. Using the official and actual wage rates, the respective benefit cost ratios were 2.2 and 1.9 for modified, and 1.5 and 1.4 for conventional rice cultivation. The remaining 64 farmers were not able to implement all the components of the modified method even though the ARTs were periodically monitored by the researchers. This demonstrates the practical difficulties both farmers and researchers faced while implementing the on-farm ARTs. The state average rice yield is around 5 t ha^{-1} (TNAU, 1999). The average yields obtained in the 36 ARTs were 6.1 and 8 t ha^{-1} for conventional and modified methods, respectively. Earlier computer simulation studies using the MACROS model showed that there is a possibility of achieving up to 9.3 t ha^{-1} yield for the conventional method in Tamil Nadu conditions (Thiyagarajan et al., 1993). The highest yield achieved in the on-farm trials was around this simulated yield, i.e. for the conventional method was 8.7 t ha^{-1} and for modified method 10.7 t ha^{-1}. The limited adoption by farmers, who were often only experimenting on a small area with the modified rice cultivation method, despite the higher income obtained appeared to be caused by other factors, and is discussed in the following section.

3.3. Farm surveys

3.3.1. Farm survey I

The farm survey conducted in 2004, 2 months after the ARTs were completed, focused on understanding farmers' experiences with the modified rice cultivation method (Van der Maden, 2006). The following observations were made: 1) farmers were positive about the modified rice cultivation method and the resulting higher yield and water saving; 2) the farmers were not sufficiently confident with the modified method to implement them without guidance from researchers; 3) farmers were anxious not to make mistakes with the modified method that could cause crop failure. Perceived risks of the modified method were related to the dapog nursery preparation, and initial crop establishment; and 4) farmers not involved in the ARTs did not know about the modified rice cultivation method and were not interested to know about the theories of the new technique. They wanted to see the methods in practice.

3.3.2. Farm survey II

The second farm survey of 2006 was designed to understand more about the internal and external factors that influenced adoption and adaptation strategy. Revisiting the farms two years after the on-farm experiments allowed us to survey the actual adoption of the modified rice cultivation method.

The increased yield and profit resulting from the introduction of the new technology was the prime factor of interest for farmers and received 16% of the 50 marks allocated (Figure. 3). Other factors in descending rank order that received more than 5% of the marks allocated were: 1) cost reductions due to reduced inputs; 2) the smaller capital investment required; 3) the scope for expansion of the farm structure and functions; 4) the lack of side-effects such as pest and diseases; 5) the scope for income diversification; 6) the suitability of the modified methods to soil and topography; and 7) that benefits of the new technology could be realized in the short term. Factors which farmers considered to be less important (that received less than 5% of the marks allocated) were ecosystem conservation, long-term sustainability and less water use (Figure. 3).

The most important factor external to the farm, with close to 25% of the marks allocated, was a good and stable price for the produce (Figure. 4). Other factors considered to be important, with 10% or more of the marks allocated, were: 1) subsidy and credit facilities; 2) climatic suitability for the new technology; 3) insurance and risk coverage in case of any failure of crop due to the new technology adoption during the period of testing; and 4) marketing facilities for the produce. External factors considered to be of less importance, with less than 10% of the marks allocated, were technical support from the government, accessibility to the machinery and inputs needed for the new technology, transport facilities and the adoption behaviour of the neighbouring farms.

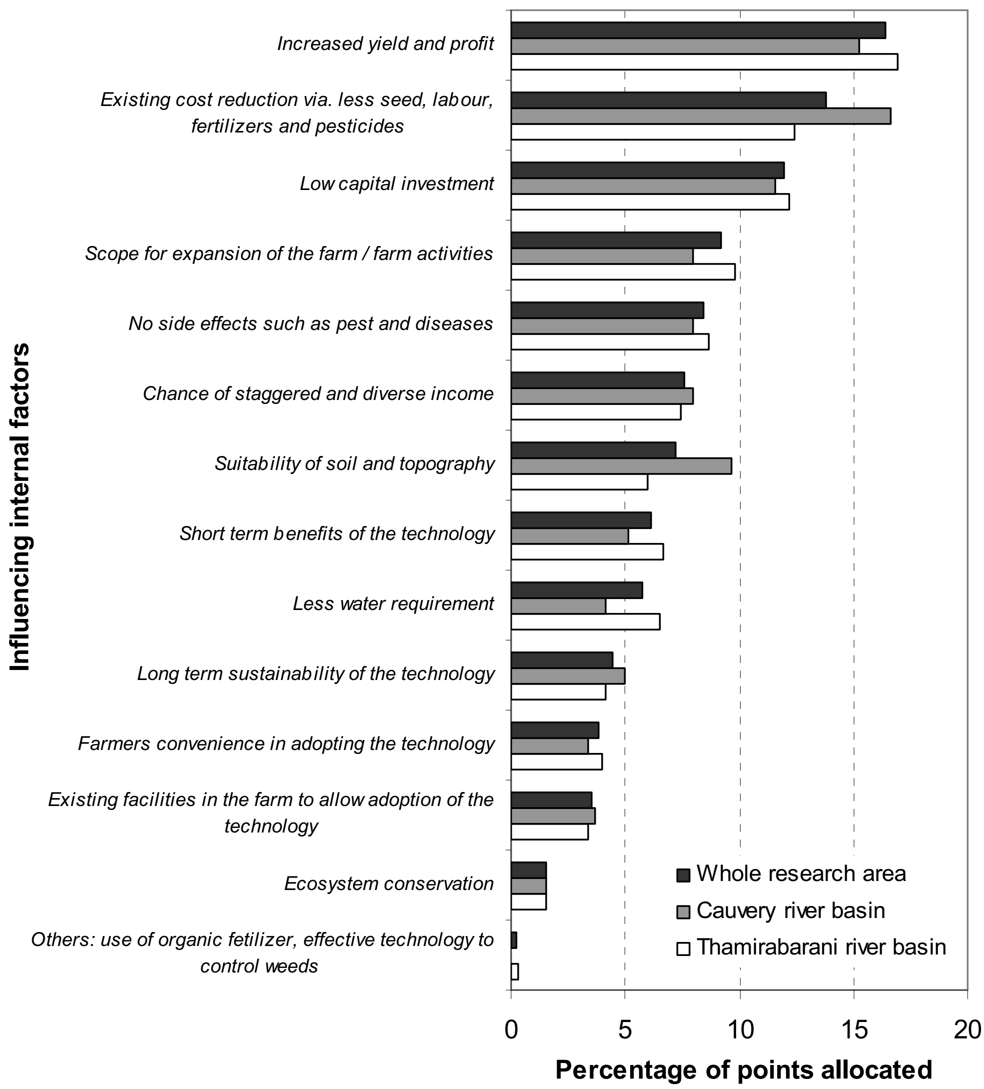

Figure 3. Internal factors influencing the farmer's new technology adoption strategies from the second farm survey in the Thamirabarani and Cauvery river basins.

Farmers' experience with yield and yield attributes obtained using the modified rice cultivation method compared positively to the conventional method (Table 5). Virtually all farmers in both Thamirabarani basin and Cauvery basin stated that rice crops cultivated with the modified method produced more tillers that were more robust, healthy and productive than crops in the conventional method. The number of unfilled spikelets was said to be less with modified rice cultivation (58% and 72% in the Thamirabarani and Cauvery basins, respectively), while the plant height and greenish look of the modified rice crop was better. Rice crop produced more straw using the modified method. Reduced pest and disease incidence was also observed with the modified rice cultivation method.

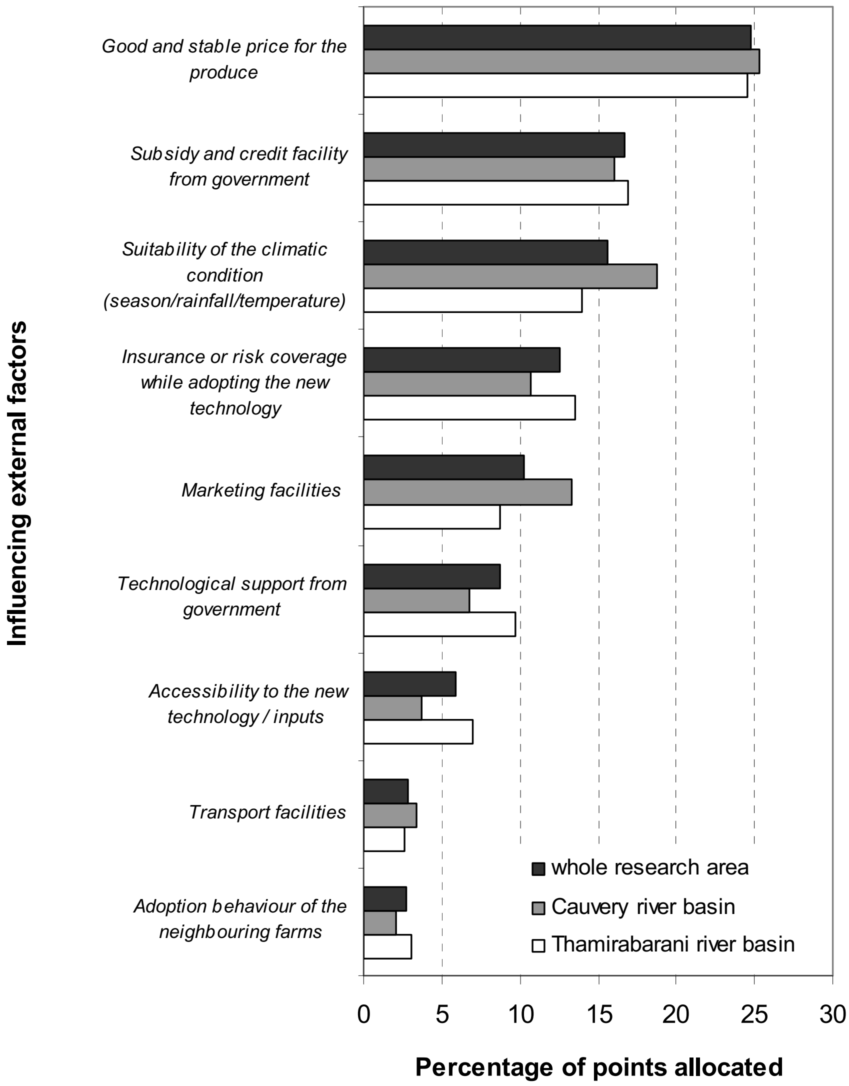

Figure 4. External factors influencing farmer's new technology adoption strategies from the second farm survey in the Thamirabarani and Cauvery river basins.

There were mixed opinions on labour requirements for the modified rice cultivation method. In neither river basin did farmers find a difference in labour requirement between the two different methods for irrigation, fertilizer application, harvesting and processing (Table 5). Farmers took little time to open and close the irrigation channels. Most of the rice fields in a command area are irrigated through the cascade method of irrigation. There was no difference in quantity and type of nutrient application between modified and conventional methods and harvesting was done using a combined harvester in both cases. For land preparation, 48% of the farmers in the Cauvery river basin reported that there was a greater labour requirement for the modified method because of the need for proper levelling of the field. This was not mentioned by farmers in the Thamirabarani basin. There was a large difference between the two basins in labour requirements for square and line planting. Of the farmers in

Thamirabarani basin, 96% experienced a higher labour requirement, while this was true for only 20% of the farmers in Cauvery river basin (Table 5). This was due to the experience labourers already had with line planting in the Cauvery river basin. The experiences in labour requirement for modified nursery preparation in both the river basins were mixed. Mechanical weeding required less labour for 80 and 76% of the farmers in Thamirabarani and Cauvery river basin, respectively.

Table 5. Farmers' experience of yield, yield attributes and labour requirements in modified rice cultivation compared with the conventional cultivation of rice in the Thamirabarani and Cauvery river basins

Modified rice cultivation methods	Thamirabarani basin (%)			Cauvery basin (%)		
	[a]High	[b]Normal	[c]Less	[a]High	[b]Normal	[c]Less
a) Yield and yield attributes in modified method compared with conventional method						
Number of tiller production per unit area	98	2	0	100	0	0
Tiller robustness	94	6	0	100	0	0
Height of the plant	74	26	0	96	4	0
Productive tiller per unit area	96	4	0	100	0	0
Greenish look of the crop	78	20	2	88	12	0
Straw yield (qualitative)	88	10	2	96	4	0
Grain yield (qualitative)	90	4	6	84	16	0
Number of unfilled spikelets	4	38	58	0	28	72
Pest and disease problem	2	24	74	4	40	56
Weed infestation problem	10	50	40	4	28	68
b) Labour requirement in modified method compared with conventional method						
Modified nursery preparation[d]	36	22	38	16	48	36
Land preparation	18	82	0	48	52	0
Square planting	96	2	2	20	28	52
Mechanical weeding[d,e]	4	6	80	16	8	76
Irrigation	2	82	16	0	100	0
Fertilizer application	4	84	12	0	100	0
Harvesting and Processing	0	98	2	0	100	0
Performing modified method as a whole	62	8	30	88	0	12

[a]High: higher in modified method than conventional; [b]Normal: no difference in both methods; [c]Less: lesser in modified method than conventional. [d]Four and ten percent of the farmers did not adopt the modified nursery and mechanical weeding, respectively. [e]Rotary weeder in case of Thamirabarani basin and cono-weeder in case of Cauvery basin.

Grain yields, converted to t ha^{-1} from farmers' estimates of bags per acre (Figure. 5), indicated that 68 of the 75 farmers interviewed harvested more rice with modified cultivation practices. Two farmers harvested poor yields using the modified method as their crop failed due to pest and disease problems, which the farmers attributed to the profuse tillering and darker green foliage.

Farmers' assessment of the modified rice cultivation method revealed a large number of difficulties in adopting the modified method. In the Thamirabarani river basin, 68%

farmers reported difficulties with square planting for the modified method while only 28% reported the same in the Cauvery river basin (Table 6). Line planting (planting in

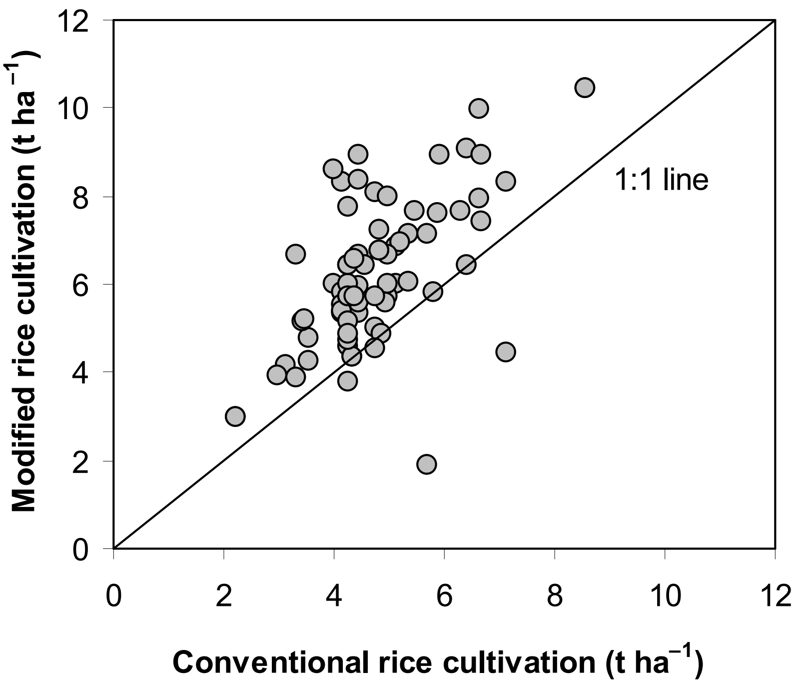

Figure 5. Yields obtained by using the modified rice cultivation method compared with those obtained at the same farm using conventional method as estimated in the second farm survey, 2006.

rows in any one direction) was also considered to be difficult by 58% and 24% of the farmers in the Thamirabarani and Cauvery river basins, respectively, compared with the conventional method of placing the seedlings randomly.

The other associated problems identified by the farmers were: 1) death of young seedlings (15 days old) in low-lying fields due to flooding which required repeated gap filling; and 2) the increased labour requirement for modified planting restricted the size of land that could be planted using the modified rice cultivation method.

The modified nursery (dapog) was considered to be more difficult to prepare than a conventional nursery by 56% of the farmers in the Thamirabarani basin and 32% of the farmers in the Cauvery basin (Table 6). Mechanical weeding was considered easy to perform compared with conventional hand weeding by 78% of the farmers in Thamirabarani river basin who used the rotary weeder. A considerable number of farmers (40%) expressed dissatisfaction with the use of the cono-weeder in the Cauvery river basin which they found difficult to handle because of its weight. As women agricultural labourers cannot operate the cono-weeder in heavy clay rice fields, farmers employed more costly male labourers for weeding.

Table 6. Farmers' and labourers' experience of different components of modified rice cultivation compared with the conventional method of rice cultivation in the Thamirabarani and Cauvery river basins (labourers' experiences are based on farmers' responses as it was not possible to interview them directly)

Modified rice cultivation methods	Thamirabarani basin (%)				Cauvery basin (%)			
	[a]Hard	[b]Normal	[c]Easy	[d]Not adopted	[a]Hard	[b]Normal	[c]Easy	[d]Not adopted
a) Farmers' experience of modified rice cultivation methods								
Land preparation	6	92	2	0	36	64	0	0
Modified nursery preparation	56	12	30	2	32	28	20	20
Line planting	58	20	22	0	24	52	24	0
Square planting	68	10	20	2	28	48	24	0
Mechanical weeding[e]	12	4	78	6	40	4	56	0
b) Farmers' opinion on labourers' experience of modified rice cultivation methods								
Line planting	86	8	6	0	72	20	8	0
Square planting	90	2	2	6	76	16	8	0
Mechanical weeding[e]	14	4	74	8	56	4	40	0
Over all opinion on modified rice cultivation	86	10	4	0	76	24	0	0

[a]Hard: practicing the modified method is more difficult than conventional method; [b]Normal: no difference experienced between the methods; [c]Easy: practicing modified method is easier than the conventional method; [d]Not adopted: that particular modified rice cultivation method was not practiced by the farmer. [e]Rotary weeder in case of Thamirabarani basin and cono-weeder in case of Cauvery basin.

Farmers were further asked about the opinion of their agricultural labourers with regard to the modified rice cultivation method, as it was not possible to interview the labourers directly. In both the basins the farmers noted that the majority of labourers complained about the modified rice cultivation method (Table 6). Most problems were experienced with the square planting method (90% and 76% in Thamirabarani and Cauvery, respectively), followed by the line planting (86% and 72%). Mechanical weeding, however, was considered to be an easy activity by labourers in the Thamirabarani basin (74%), whereas labourers in Cauvery basin were less satisfied (40%) because of the heavy cono-weeder.

The major suggestions from the farmers on improvement of the modified cultivation method were: that free incentives from the government should be given to those practicing the modified method (49%); more demonstration trials and training were needed (43%); solutions need to be found to reduce the labour requirements for planting through introduction of planting machines for the square planting (25%). The above three suggestions reflect the higher costs, lack of experience and higher labour demand for planting with the modified rice cultivation method. The other suggestions were: that there should be more co-operation and involvement of extension officials in spreading the modified method (15%); training should be given to agricultural labourers on the new techniques since they actually do the work in the fields (12%); a higher minimum support price should be given for rice and more marketing facilities would create interest from the farmers on rice cultivation (8%); the mechanical weeder should be modified to suit weeding operations even in deep clay soils (5%); and the adoptive research trials should be implemented in a large area through village level agreements on irrigation scheduling rather than in single field demonstrations (4%). Modernizing the irrigation delivery systems to prevent unwanted flooding of rice fields and provision of a fair and efficient extension system while introducing the modified rice cultivation method was suggested by a few farmers.

In the Thamirabarani basin, 16% of farmers were practicing the modified rice cultivation method compared with 56% in the Cauvery basin. Of these farmers, however, only 2% (Thamirabarani) and 4% (Cauvery) were practicing the modified cultivation method on the entire area of rice cultivated. The total land holding of the 50 farms surveyed in the Thamirabarani basin was 138 ha of which 8 ha (6%) was under modified rice cultivation. In the Cauvery river basin the total land holding of the 25 farms surveyed was 98 ha of which 6 ha (6%) were under modified cultivation.

Farmers' opinions on modified rice cultivation method were verified on the basis of their spontaneous response to the question "Any problems with modified rice cultivation?" A similar proportion of farmers in both basins mentioned modified planting required more labour (Table 7) and 36% and 12% farmers mentioned that the women labourers were unwilling to do square planting in the Thamirabarani and Cauvery river basins, respectively.

In both river basins, rice growers start to plant rice when water was released from the canal for irrigation which led to a peak demand for labour at planting. Practicing the modified method of planting led to increased scarcity of labour. Since square planting was advised to be done using ropes and marker sticks, labourers who are less experienced with this modified planting method take more time to plant the same area than with conventional planting method. The women agricultural labourers complained that handling young seedlings (15 days old) and maintaining proper spacing in between rows and plants in rows simultaneously were difficult and that they would object if the farmer would want them to plant using the modified planting method. Moser and Barrett (2003) also found that planting young seedlings in a square pattern was difficult for farmers in Madagascar because the method required significant additional labour input at a time of the year when liquidity was low and labour was scarce.

The farmers considered that irrigating the modified nursery using a watering can three times a day was time consuming. In addition, in both basins, 24% of the farmers mentioned preparation of the dapog nursery was a problem (Table 7). The uncertainty of the timing of water release from the canal for irrigation also made dapog nursery preparation problematic. Any delay in water release, so that seedlings were older than 20 days, led to intertwining of the roots, making the seedlings unfit for planting. By contrast, in conventional nurseries, farmers can maintain the seedlings until they receive water from the canal as no seedling damage occurs.

Table 7. Problems experienced by farmers in the Thamirabarani and the Cauvery river basins while practicing modified rice cultivation and farmers suggestions to improve the modified methods. (Data collected during the farm survey in 2006, total of 75 farms surveyed, 50 from Thamirabarani river basin and 25 from Cauvery river basin)

Description	Farmers' experience (%)		
	Thamirabarani river basin	Cauvery river basin	Whole survey
a) Problems observed by farmers while practicing modified rice cultivation			
Increased labour requirement for planting	68	24	53
Unwillingness of agricultural labourers to change practices	36	12	28
Difficulties with modified nursery practices	24	24	24
Difficulties with mechanical weeding	2	52	19
Difficulties with practicing water-saving irrigation	6	28	13
Waterlogging in low-lying rice fields	8	20	12
Problems with whole area adoption	14	8	12
Risk and uncertainty of water release	12	4	9
Time consuming and more personal care requirement	8	4	7
Problem with monsoon season	0	16	5
Farmer's personal constraints	2	4	3
b) Suggestions to improve modified rice cultivation			
Free incentives from government	44	60	49
More training and demonstration trials	36	56	43
Scientific advancement to reduce labour for planting	24	28	25
More involvement of extension officials	18	8	15
Training to agricultural labourers	14	8	12
Higher minimum support price for paddy and more marketing facilities	10	4	8
Simplifying mechanical weeder	0	16	5
Village level agreements on irrigation scheduling	6	0	4
Fair and efficient extension system and modernizing irrigation delivery structures	2	0	1

The majority of the farmers (82% and 96% in Thamirabarani and Cauvery river basin, respectively) in the sample practiced water-saving irrigation on part of their land. The remaining 18% and 4% farmers from the respective river basins could not practice water-saving irrigation as their fields were under a cascade system of irrigation.

Farmers could not use water-saving irrigation when the surrounding farmers flooded their fields. Water-saving irrigation was also not possible during the monsoon season as the heavy rains flood the fields.

A number of other problems were mentioned by the farmers. Even after mechanical weeding there was a need to employ women labourers to remove weeds close to the rice hills by hand. The modified method required proper levelling of the fields and led to delayed maturity of the crop because the use of younger seedlings led to a longer crop cycle. This meant that harvest was delayed until after neighbouring farmers harvested their crop which was construed by their neighbours to result from the farmer’s poor management skills. The modified rice cultivation required more care and attention from farmers who often were engaged in secondary occupations, or were elderly and did not want to invest extra time in their fields.

During the farm survey, an attempt was made to understand the interest of the farmers to adopt the modified method in the future. Nearly 30% of the farmers in the Thamirabarani and 8% in the Cauvery basin said they did not intend to practice the modified cultivation method. A majority of the farmers surveyed in both river basins (70% and 92%) were willing to continue with experiments on the modified cultivation. More than half of the farmers wanted to undergo more training and expected logistic support of government through direct or indirect subsidies, credit facilities and knowledge support from scientists and extension services.

Farmers in both river basins were still experimenting with modified rice cultivation in a small portion of their rice fields. The farmers had no direct say on the timing of release of canal water for irrigation, and therefore used as much water as possible when they had access to it. Farmers who had bore hole wells were provided with free electricity for pumping. As water was also provided free of charge, there was little incentive for individual farmers to reduce the amount of water that they used. Changes in policy that may encourage water-saving irrigation include the introduction of charges for irrigation water and electricity.

4. Conclusion

Although the experimental results, both on-station and on-farm, indicated that water saving of 40–50% was possible without any negative effect on rice yields, farmers interest in adoption of the practices was mixed. The farmer-managed on-farm experiments indicated that modified rice cultivation method gave better yields, and these advantages were clear to the farmers. Yet practicing the modified rice cultivation farmers had a number of practical difficulties including the need for more time and labour for the modified planting method, difficulties with dapog nursery preparation and the shift from women’s labour to men’s labour for mechanical weeding. As water is provided free of cost to the farmers, they tend to flood their rice fields when the canal water is released as water availability for a next irrigation was not guaranteed. Given the inconvenience for farmers in changing their management practices, despite yield gains found with the modified rice cultivation method, changes in policy will be required to encourage adoption of water-saving irrigation.

Acknowledgements

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Chapter 3

Characterising rice-based farming systems to identify opportunities for adoption of rice cultivation modified to save water in Tamil Nadu, India[†]

[†] Adapted from:

Senthilkumar, K., Bindraban, P.S., de Boer, W., de Ridder, N., Thiyagarajan, T.M., Giller, K.E., 2008. Characterising rice-based farming systems to identify opportunities for adoption of rice cultivation modified to save water in Tamil Nadu, India. Agricultural Water Management. Submitted.

Abstract

Efficient water use in rice cultivation is a prerequisite to sustain food security for the rice consuming population of India. Novel rice production practices, including water-saving techniques, modifications in transplanting, spacing, weeding and nutrient management, were developed and showed to be effective on rice-based farms, but adoption of these techniques remained restricted. Potential constraints included technical difficulties with new cultivation practices, labour and gender issues which differed between farms. On the basis of a rapid survey of 100 rice-based farms, four farm types were identified based on their socio-economic and biophysical characteristics using principal component analysis (PCA). Detailed farm surveys were then conducted on three representative farms of each farm type to evaluate land use patterns, use of inputs such as water, labour, nutrient, capital and machinery, income from crop and animal production and off-farm activities. Farms of Type 1 were large farms, with ample access to water, agricultural inputs, machineries and cash for investment. The farmers of these farms earned a large share of their income through off-farm activities. Farm Type 2 comprised of farms where household members were fully engaged in agriculture, although off-farm activities such as hiring out of their labour and farm machines contributed ~50% of their moderate income. Farmers of Type 3 were the poor who raised crops mainly for household consumption. Farming depended on a limited land holding with only external water resources. Farmers of Type 4 faced water scarcity in rice cultivated for home consumption and farm production depended on the monsoon rainfall and stored water resources. Opportunities exist to adopt one or more techniques to modify rice cultivation in all the four farm types. For all farm types, however, the opportunities for adopting water-saving irrigation were found to be the least promising. In general, adoption of water-saving irrigation will not improve farmers' livelihoods effectively despite its importance in reducing water scarcity problems at regional scale. At farm scale, potential for adoption of water-saving irrigation depends on the season, location of fields and the irrigation source across all farm types. Change in government policies such as rules and regulations, pricing, institution building and infrastructure development, as well as training and education of farmers are needed to improve the adoption of modified methods for rice cultivation.

Keywords: Farm characterisation, farm typology, principal component analysis, technology adoption

1. Introduction

Water is becoming a scarce commodity for agricultural use as demand continues to increase (Barrow, 1987; Ellis, 1988; English, 1990; Brugere and Lingard, 2003). Continuous population growth and industrialization compete for their share of the available water resources which makes farming, and in turn farmers, vulnerable. In India, not only water, but also land is becoming a constraint as nearly 90% of the farmers have land holdings smaller than 2 ha. For example, in Tamil Nadu the number of smallholder farmers increased from 4.2 million in 1970s to 7.4 million in late 1990s with increasing fragmentation of land (State Planning Commission, 2004). The reliance on rainfall is high, and the low and erratic nature of rainfall during the monsoons in this semi-arid region leads to moisture deficits for crop production. While farmers may receive irrigation water, they have little control over its availability as irrigation boards are responsible for the supply. Water availability is further jeopardized because of the falling groundwater tables from 5-10 m below the soil surface some two decades ago to almost 60-100 m depth (Public Works Department, 2004). The deficient and uncontrolled availability of water entails high risk to crop failure and hampers investment in farming. The resulting poor agricultural productivity and high vulnerability of rice production places the farmers, who also have to cope with uncertain prices for agricultural produce, in situations from which it is difficult to escape poverty.

Rice (*Oryza sativa* L.) is the predominant crop in Tamil Nadu and its cultivation consumes 70% of the available water for agriculture (Thiyagarajan et al., 2003). One way for farmers to minimize risk of crop failure is to over-irrigate rice crops, which is particularly attractive if irrigation water is available free of charge. This leads to inefficient use of water and low water productivity in rice cultivation.

The introduction of a series of rice production techniques, including water saving, is a recent development in Tamil Nadu. These rice cultivation techniques were tested in on-station and on-farm experiments between 2001 and 2005. The main modifications in cultivation were: 1) irrigation - conventional flooding (up to 5-10 cm) replaced by keeping a thin layer of water (2 cm) up to flowering; 2) planting - random planting of more than 24 day-old seedlings replaced by square planting of less than 15 day-old seedlings in wider spacing; 3) weeding - hand weeding replaced by mechanical weeding using rotary or cono weeder; and 4) nutrient management - only mineral fertilizers replaced by organic manure combined with mineral fertilizer. On-station experiments gave an overall water saving of 40-50% without any reduction in yield and water productivity increased by 40-47% (Thiyagarajan et al., 2002; Senthilkumar et al., 2008). Planting young seedlings in square pattern and mechanical weeding increased the grain yields significantly while application of organic manure increased the grain yield when combined with modified planting and mechanical weeding (Thiyagarajan et al., 2002; Thiyagarajan et al., 2003; Senthilkumar et al., 2008).

Subsequent on-farm experiments in 200 farms confirmed the possibility of modified rice cultivation techniques with larger yields than rice cultivation using conventional practices. Farm surveys conducted to understand farmers' experience with these novel practices indicated that the farmers were impressed by the yields obtained and the savings in water use. However, a number of constraints hampered the adoption of the novel practices, including difficulties with irrigation scheduling, extra labour requirement and unwillingness of agricultural labourers for square planting, difficulties with modified nursery preparation and a shift from women's labour for hand weeding to men's labour for mechanical weeding (Senthilkumar et al., 2008).

Potential for adoption of novel practices depends on the structure and functioning of the farm. Therefore, a comprehensive understanding of farm characteristics is a prerequisite to understanding the factors that determine adoption. These characteristics include on- and off-farm activities, farm size, irrigation source, water and labour availability, use of other inputs and farmer knowledge of the new technologies. As each farm household is unique, and we cannot explore the future options for each individual farm, we need to categorise them. Farm typologies are a means of categorizing farms, where farm types are inferred from the farm characteristics, generally using multivariate analysis and clustering techniques (Duvernoy, 2000). Different approaches have been used to group farms based on criteria such as land size of a farm (Duvernoy, 2000), area of the various crops per farm and the availability of labour and equipment (Leenhardt and Lamaire, 2002) and mode of survival and survival strategies (Daskalopoulou and Petrou, 2002). Tittonell et al. (2005) classified farm types using socio-economic information, production activities, household objectives and the main constraints faced by farmers. Further, farms have been classified based on absolute characteristics of the farm and rates of structural change to analyse differences in agricultural trajectories (Iraizoz et al., 2007), or on the relative distribution of the farm income (economics) coming from different production sources (field crops, dairy cattle, etc.)(Andersen et al., 2007).

In this study, we categorised farms based on resource endowments, i.e. quantifiable biophysical (e.g. land, labour and water availability) and socio-economic (e.g. education, wealth) characteristics of the farm and its family. The objectives of our study were: 1) to understand the farm structure and functioning of rice based farming systems; 2) to group them into different farm types using characteristics that possibly determine adoption of novel rice cultivation practices; and 3) to assess the opportunities and constraints for farmers in each farm type to adopt these practices.

2. Materials and methods

2.1. Farm typology

A rapid farm survey was conducted in the rice-based farms of Thamirabarani river basin situated in the southern part of Tamil Nadu, India. The river starts in the Western Ghats and ends in the Bay of Bengal, and the basin lies between 8º45'and 9º23' latitude and 75º13'and 77º54' longitude. The basin was chosen because on-farm water-saving experiments had been carried out here (Senthilkumar et al., 2008). A hundred farms were selected to represent the rice-based farms situated in both the area in the catchment where no irrigation water is received from the river and the command area that receives irrigation water (Figure 1). The proportion of rice-based farms in the river basin is 43% which is higher than the state average of 34% (Statistical Hand Book, 2006). Farms were selected by asking the village head and local people to identify farmers who cultivate at least one rice crop a year. Since one of the objectives of this study was to explore adoption of the novel practices in rice cultivation, 35 out of 100 of the farms surveyed were randomly selected from the group that participated earlier in the on-farm experiments. The other farms were randomly selected from the farmers that grew rice but had not participated in earlier experiments. The steps followed in the farm surveys, selection of farms, data collection and analysis are summarised in Figure 2.

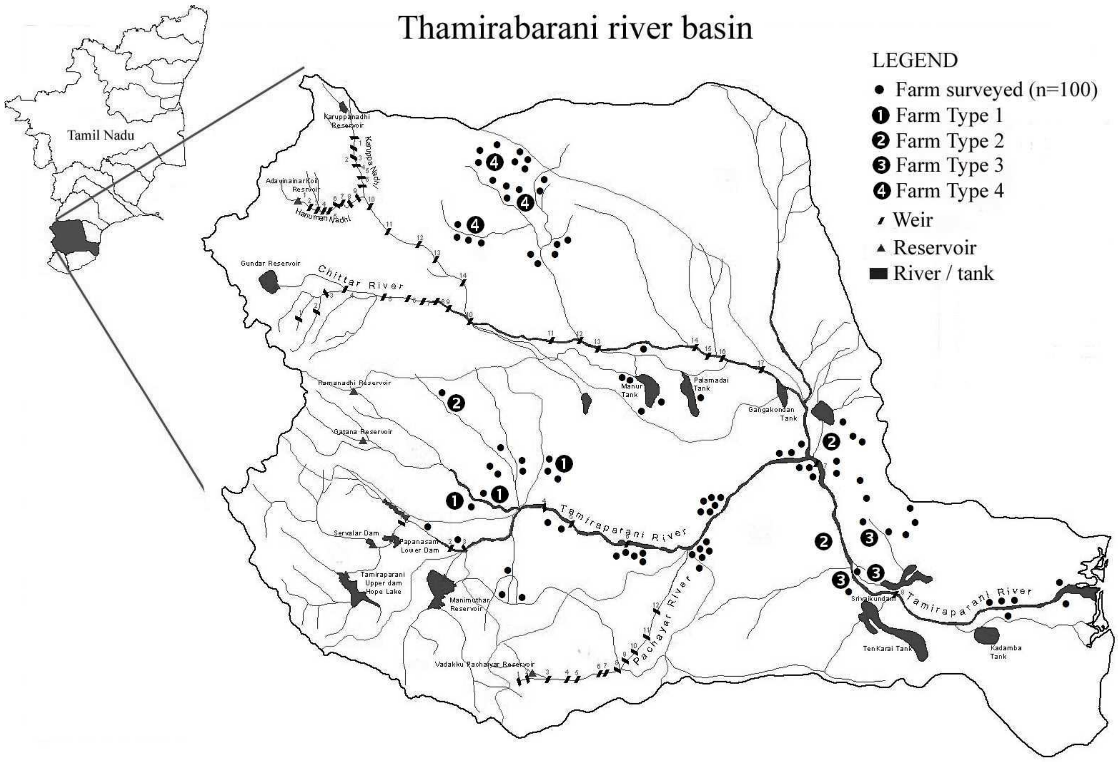

Figure 1. Location of Thamirabarani river basin in Tamil Nadu, India. The farms surveyed (n = 100) and sample farms (n = 3 per farm type) for detailed survey are indicated.

The questionnaire used to generate a typology of farms in western Kenya (Tittonell, 2003) was modified to fit the categorisation of rice-based farms in Tamil Nadu.

Information was obtained on farm size and number of rice crops in a year, farm family characteristics like age and main occupation of the farmer, total household members, education level of the farmer and his family, and farm wealth. Family labour availability was calculated from the number of family labourers working full time or part time on the farm and the presence of permanently hired labourers. The number of temporarily hired labourers was not accounted in this survey since the farmers did not keep records. The presence of animals (bullocks, dairy cattle, sheep, goats and chicken), and their number per type as well as the possession of farm machines and implements were recorded. Information about available irrigation facilities and the land area irrigated using different irrigation sources was collected. Farm wealth was categorised in three classes with class 3 regarded as the wealthiest and 1 as the poorest. Variables that served as wealth indicators were farm size (> 4 ha (class 3); 2-4 ha (class 2) and < 2 ha (class 1)), type of house owned (concrete (3); tiled (2); thatched (1)), possession of assets such as vehicles (car (3); motor bike (2); cycle/none (1)), pieces of electric apparatus (>2 pieces (3); 2 pieces (2); >one piece (1),) and farm machines and implements (tractor/power tiller (3); plough (2); none (1)). The wealth classes were defined based on the farmers' scores on the above five indicators. For example, if a farmer scored the first category in more than three of the wealth indicators he was classified as wealthy. In total, 23 farm resource endowment characteristics were identified and used (Table 1).

Step 1 →

- Rapid farm survey in 100 farms, including 35 farms that had experience with modified rice cultivation
- Identification of 23 farm variables for farm typology analysis.
- Identification of 4 farm types using the principal component analysis (PCA).

Step 2 →

- Sample of 6 farms were selected per farm type to describe each farm type characteristics.
- Explained the differences in characteristics of identified farm types using the 23 farm variables used for farm typology.

Step 3 →

- Sample of 3 farms were selected from the already sampled 6 farms in each farm type for detailed farm survey.
- The structure and functioning of each farm type quantified using the 3 sampled farms as 3 replications.
- Described the structure and functioning of each farm type quantitatively using the average values of 3 farms per farm type.

Figure 2. Steps followed for data collection and analysis to understand the farm characteristics in the study.

Table 1. General farm characteristics of four different rice-based farm types in Thamirabarani river basin. The minimum, maximum and mean values of 23 farm resource endowment characteristics of 6 sample farms per farm type are presented.

Farm variables used for farm type classification	Farm Type 1			Farm Type 2			Farm Type 3			Farm Type 4		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Land holding and rice cultivation												
Farm size in ha (FSE)	4	12	7.1	2	6.8	4.1	0.3	0.8	0.5	1.2	4	2.1
Number of rice crops per year (NOR)	1	2	1.8	1	2	1.5	1	2	1.2	1	1	1.0
Farm family characteristics												
Age of the farmer (AOF)	30	74	43.7	52	66	57.3	34	62	49.0	38	67	53.5
Education level of farmer (ELF)*	2	3	2.7	1	2	1.3	1	2	1.2	1	2	1.2
Average education level of the farm family (AEF)*	2	3	2.7	1	2	1.2	1	2	1.5	1	2	1.5
Major occupation farming/others (MOC)*	1	2	1.5	2	2	2.0	2	2	2.0	2	2	2.0
Total household members (TPF)	4	11	6.8	5	12	8.5	4	6	5.2	2	5	3.8
Farm wealth (FWL)*	3	3	3.0	2	3	2.3	1	1	1.0	1	2	1.8
Farm labour availability												
Number of family labourers working fulltime in the farm (WFF)	0	3	1.0	0	6	2.8	0	2	0.7	0	1	0.2
Number of family labourers working part time in the farm (WPF)	0	2	0.8	0	4	0.7	0	3	1.7	1	3	2.0
Number of permanently hired labourers (PLA)	2	4	2.3	0	0	0	0	0	0	0	0	0
Presence of animal units												
Number of Bullocks (BUL)	0	2	0.7	2	4	2.5	0	2	0.3	0	0	0
Number of Dairy animals (DAI)	0	9	2.8	2	8	4.5	0	5	3.0	0	0	0
Number of Sheep (SHP)	0	2	0.3	0	0	0	0	2	0.7	0	1	0.2
Number of Goat (GOT)	0	0	0	0	12	4.7	0	10	1.7	0	0	0
Number of Chicken (CHK)	0	4	0.7	0	20	7.2	0	10	4.7	0	4	1.2
Farm mechanization												
Number of farm implements (hand operated) owned (FEQ)	0	2	1.3	1	5	2.8	0	2	0.3	0	1	0.2
Number of farm machines (power operated) owned (FMA)	0	3	1.7	0	2	0.8	0	0	0	0	1	0.2
Available irrigation sources												
Farm area irrigated by canal and well in ha (CTW)	0	4.8	0.8	0	6	1.4	0	0	0	0	0	0
Farm area irrigated by canal alone in ha (CTI)	0	10	4.6	0	3.2	1.1	0.3	0.8	0.5	0	0	0
Farm area irrigated by well alone in ha (WIA)	0	4	1.7	0	4	1.5	0	0	0	0	0.8	0.2
Farm area irrigated by rain fed tank and well in ha (RTW)	0	0	0	0	0	0	0	0	0	0	3.2	1.3
Farm area irrigated by rain fed tank alone in ha (RFT)	0	0	0	0	0	0	0	0	0	0	1.2	0.4

* Descriptive variables are grouped as follows: For FWL, 1 = Poor; 2 = Medium; 3 = Wealthy. For ELF, 1= 0 to 8th standard; 2 = 9 to 12th standard; 3 = Graduate. For MOC, 1= Major occupation not farming; 2 = Major occupation farming. For AEF, 1 = < 1.5 of ELF; 2 = 1.5 to 2.4 of ELF; 3 = 2.5 to 3 of ELF.

Data were analysed with Principal Components Analysis (PCA) using the statistical package Canoco for Windows version 4.5 (Ter Braak, 1995; Ter Braak and Smilauer, 2002). The resulting ordination diagram was used to categorize farms (Figure 3). After identifying the Farm Types, 6 farms for each farm type (two near to the average point, two remote and two intermediate ones) were selected and used for generating the farm types. Of the six farms in each Farm Type, three were selected for detailed monitoring based on farmers' willingness, interest and co-operation to participate.

2.2. Detailed characterisation

All the selected farms were then monitored in detail for a whole year (2005-2006). This covered all three seasons, Pishanam (October, 2005 to January, 2006), Summer (February to May, 2006) and Kharif (June to September, 2006). Per farm, land used for cropping per season was quantified by observing the land under crop cultivation and land left fallow. Water inflow to the field from canals, system tanks (tanks that are fed by canals from the river and that provide irrigation water for a longer period than canals), and rainfed tanks was measured using a Parshall flume. For frequently irrigated crops like rice and banana, water inflow was measured periodically and multiplied by the number of irrigations to estimate total water use. Water use from wells was measured by calibrating the electric/diesel motor discharge rate and recording the duration of pumping. Rainfall was measured using rain gauges installed in each farm. Seasonal family labour use (labour days of 8 hours) were quantified based on the real time spent on each operation at field scale. The quantity of agricultural inputs such as seed, manure and chemical fertilizer, and other agro-chemicals applied to each crop unit was quantified on a weekly basis and summed to seasonal and annual basis. The number of permanently and temporarily hired labourers and corresponding hiring charges were recorded. Farm implement (i.e. plough, sprayer) and machine (i.e. tractor, rice harvester) hiring hours and costs were recorded. Income earned from crop, animal and off-farm activities were calculated per farm. The cost of cultivation for each crop was calculated from costs of inputs. Gross income was calculated from the marketable produce and their price. Net income per farm activity was derived by subtracting the cost of cultivation from the gross income. The value of the products consumed within the farm was calculated using market prices. Farm level data on cost of cultivation, gross and net income were calculated by summing up the values of all activities.

Calculating the income from livestock activities was difficult because of the multifunctional purpose of animals. Agrarian households in developing countries keep livestock for food, manure, draught power, accumulation of wealth, security against contingencies and for social status (Moll, 2005b). In this study, income and expenditure from livestock activities were calculated based on the value of recurrent products (e.g. milk) and purchased feed. The embodied production values (e.g. unsold fattened animals) were not included. The feed provided to the animals from the farm (e.g. rice straw) and family labour used for animal care were assumed to be free of cost. Purchase and selling of animals was considered as expenditure and income, respectively. Off-farm income earned through jobs, pension, private business, renting of machines and implements to other farms and hiring out of family labour to neighbouring farmers were quantified.

Averages per farm type (n=3) were calculated for all characteristics. The opportunities and constraints in adopting the four major practices of the modified rice cultivation namely, water-saving irrigation, modified planting, mechanical weeding and organic manure application were analysed for each farm type.

3. Results and discussion

3.1. Farm typology

The PCA of the rapid survey data of 100 farms using 23 farm resource endowment characteristics. This generated two first principal components that explained 24% and 9% of the total variance (Figure 3). Farm variables such as farm machinery (FMA), average education level of the farm family (AEF), education level of the farmer (ELF), farm size (FSE), farm wealth (FWL), and presence of permanent hired labour (PLA) were positively related to each other, whereas farm machinery (FMA) and major occupation of farmers (MOC) were negatively correlated (Figure 3). The length of the arrows in Figure 3 shows the importance of the variable in the principal components, e.g. the presence of bullocks (BUL) and dairy cattle (DAI) are far more important variables in determining farm character than sheep (SHP).

On the basis of the PCA and a subsequent cluster analysis that lead to no clustering (not reported here), we concluded that the two principal components explain little of the variance and variance was very large between farms. Then, no categorisation of farm types in the proper sense was allowed. Farms, however, situated close together around the centroid point of a quadrant in Figure 3 are similar. We therefore decided to consider farms that were in the circles as indicated in the figure can be grouped. For the sake of simplicity we considered these groups as farm types. Farms that were close to or on the x- or y-axis could easily shift from one quadrant to another, the reason why we selected farms within the circles (n=6 per farm type) to describe the farm types (Table 1) and three out of these 6 farms per farm type to conduct the detailed characterisation.

The number of farms per farm type matched the existing state classification of farm households based on land holdings. At the state level, Farm Type 1 and 2 (n=32; % of the sample) comprised 10% of the farm households and were cultivating 56% of the farm land. On the other hand, Farm Type 3 and 4 (n=68; % of the sample) comprised 90% of the farm households and they were cultivating 44% of the farm land (Statistical Hand Book, 2006). Targeting adoption of modified rice cultivation on 10% of the farmers will itself cover more than half of the rice area in that region.

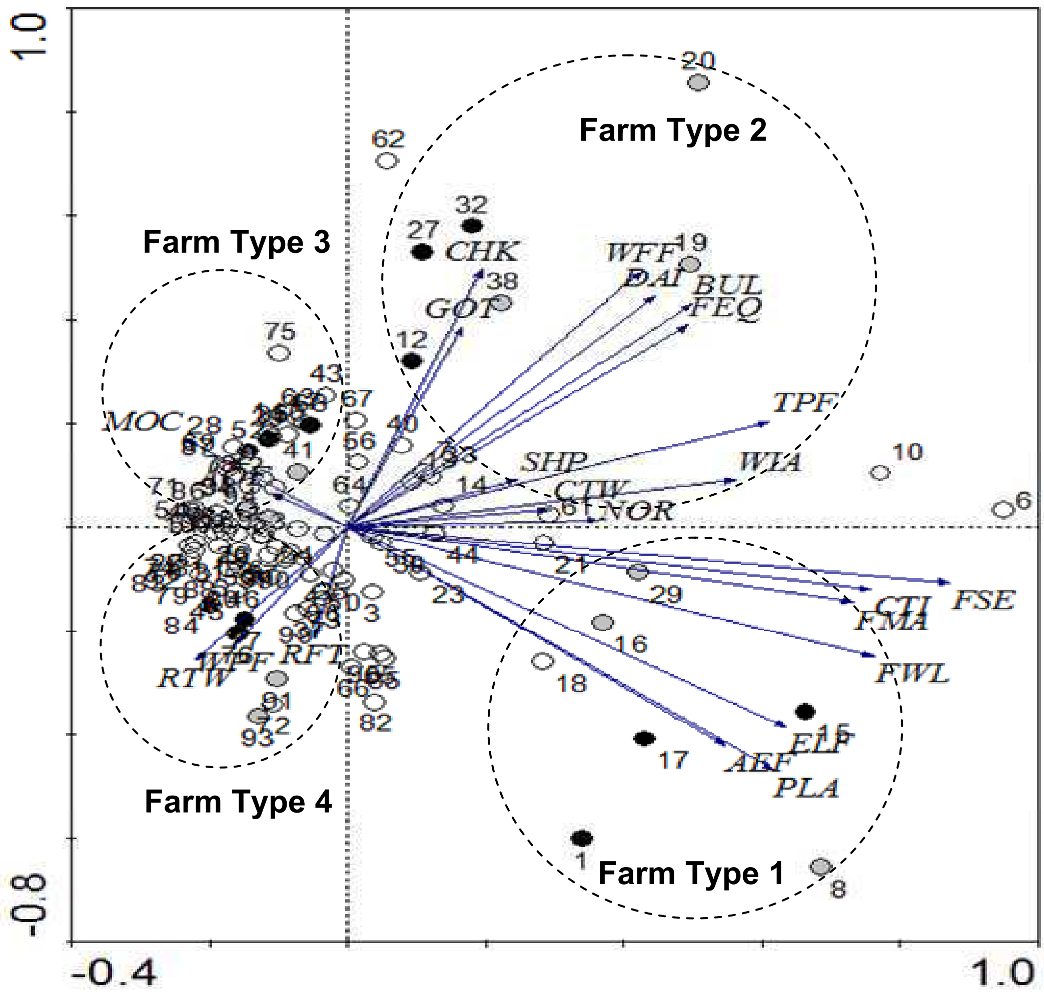

Figure 3. Picture showing the results of Principal Component Analysis for farm type classification. The x- and y-axis represent the principal component 1 and 2. The length and direction of the arrows indicate the influence of the each farm variable on the principal components. The dots with numbers indicate farms. Black and gray colored farms (n = 6) were selected for farm typology description. The gray farms (n = 3) were selected for detailed farm survey.

3.1.1. Characteristics of Farm Type 1 (x, -y quadrant)

The farmers of Farm Type 1 were, relatively speaking, the wealthiest (Wealth class 3, Table 1). They had large land holdings (average 7.1 ha). The farmer and other family members were highly educated; mostly graduates. For a considerable proportion of these farmers, farming was not their primary occupation. Although the farm households had a large number of members, only 26% of their total labour was devoted to farming, due to either full or part time off-farm employment. All farms in this group engaged at least two labourers on a permanent basis to manage day-to-day farming activities. The permanently hired labourers were paid monthly at fixed wage rates. The farmers owned more dairy animals than other livestock like bullocks, sheep, goats and chicken. The dairy animals were primarily used to meet the daily milk requirement of the family. These farmers possessed large machines such as tractors, power tillers and threshing machines, which meant they did not need bullocks for draught power. These farms were well-equipped with irrigation facilities. Overall, 64% of their land holdings had access to canal irrigation, 24% to well irrigation and the remaining 12% to both canal and well irrigation (Table 1).

3.1.2. Characteristics of Farm Type 2 (x, y quadrant)

Farmers in this group belonged to the wealth class 2 or 3 (i.e. medium-wealthy or wealthy). They had 4.1 ha on average and grew one to two rice crops a year. None of the farmers, or their family members was educated beyond primary and secondary school. All farmers in this group practiced agriculture as their primary occupation. The family size was comparatively large (average 8.5 persons) and 41% of the family members worked either full time (33%) or part time (8%) in the farm. Farms in this group had the largest number of animals per livestock category. Some farmers in this group had farm machines such as tractors, power tillers and rice threshers. Most of the farmers possessed several hand-operated implements like sprayers and ploughs, associated with the large number of working persons in the farm. These farmers had access to canal, well or both sources of irrigation water. Some 37% of the land was under canal irrigation, 27% under well irrigation and the remaining 37% land was irrigated from both canal and well.

3.1.3. Characteristics of Farm Type 3 (-x, y quadrant)

Farmers of Type 3 were comparatively the poorest (wealth class 1). This type consisted of very small landholders (average 0.5 ha) and average family size was around 5. Most farmers cultivated one rice crop a year; 20% of these farmers had a second rice crop. The farmer and family members had no more than primary and secondary school education. Farming was the primary occupation of all farmers. Nearly half (46%) of the family members worked full time on their farms and 33% part time. They cultivated crops mainly to meet their family food requirements. They were mainly agricultural labourers, who worked on other farms most days during the cropping seasons. Farmers in this group also kept a few livestock. They had no farm machines and only a small number of farm implements. Farmers had only access to canal water for irrigation which makes them vulnerable to water shortage in the later stages of the cropping season.

3.1.4. Characteristics of Farm Type 4 (-x, - y quadrant)

Farmers in this group belonged to wealth class 1 or 2, i.e. poor or medium-wealthy. They had 2.1 ha on average and grew only one rice crop a year. None of the family members were educated beyond primary and secondary school. Their primary occupation was farming. Farmers in this group had the smallest families and 58% of the family members work on the farm for about half of their time. Only 5% of the family members worked full time on the farm which implies that 95% of the farmers had a secondary occupation. These farmers own few livestock and only few farmers in this group had farm machines or implements. These farms did not have access to the canal water and cultivated crops only during the monsoon season irrigating crops in the latter growth stages with water stored in rainfed tanks or from wells.

3.2. Detailed farm characterisation

3.2.1. General cropping and land use pattern of farm types

Location of the land (upland or lowland), water sources and cropping seasons played a crucial role in determining the land use patterns of all farms. In the study area, three cropping seasons are distinguished in a year. These are Kharif (June-September), Pishanam (October-January) and Summer (February-May). The cropping period, however, is not always confined to a particular season. Overlap of cropping between seasons is not unusual, depending on the onset of the monsoon, the timing of water released in the canals and the duration of the crops cultivated.

The general cropping calendar of the four farm types is depicted in Figure 4. In Farm Types 1, 2 and 3, two rice crops a year were cultivated. The first Kharif rice crop was transplanted in June synchronising with the release of water from reservoirs. The second Pishanam rice was cultivated by all farmers of all four farm types using monsoon rainfall. This was the only rice crop in Farm Type 4. Rice was the preferred crop in this season as the intensive rainfall (70% of the annual rainfall) excluded crops that cannot withstand waterlogging. Any water requirements during the last stage of crop growth was met with both canal and well water in Farm Type 1 and 2, only with canal water in Farm Type 3, and with the stored water in rainfed tanks and well water in Farm Type 4.

Banana (*Musa spp.*) was the second major crop in Farm Types 1, 2 and 3 but was not cultivated by farmers in Type 4. On the non-flooded upland areas, Type 1 farmers cultivated perennial crops such as flowers (*Rosa chinensis Jacquin* and *Jasminum* spp.) and vegetables (*Solanum melongena* L., *Abelmoschus* esculentus (L.) Moench), but they did so only on a small area since family labour was limited and the local market easily satisfied. Improving transport and storage facilities for perishable products could generate important gains in production in these areas (Gill and Poulter, 1998). In Summer, farmers of Type 2 cultivated black gram (*Vigna mungo* (L.) Hepper) as a relay crop i.e. pulse crop seeds sown in the standing crop of rice just before harvest. Or, a green manure crop, daincha (*Sesbania bispinosa* (Jacq.) W. Wight) was cultivated on the land where rice was grown in the previous two seasons (Kharif and Pishanam). Daincha and black gram were cultivated to improve soil fertility, using residual moisture and one or two supplementary irrigations from wells (Figure 4). In the Kharif season, monocrops of vegetables and pulses were cultivated in addition to the main rice crop by Type 1 farmers using well irrigation.

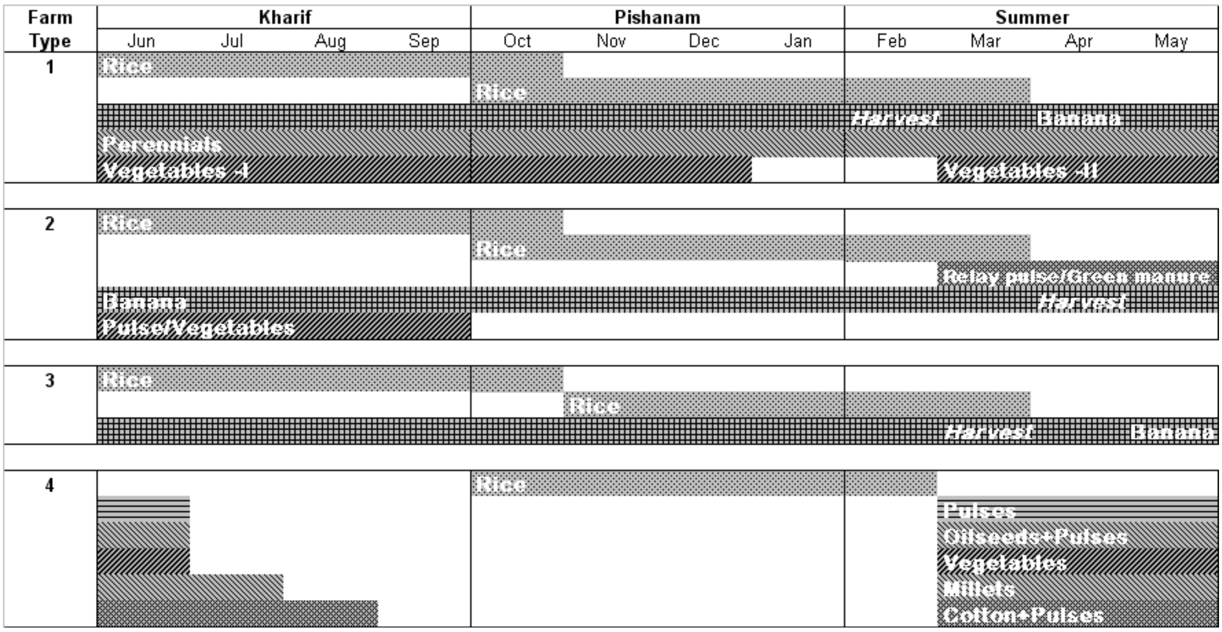

Figure 4. General crop calendar per farm type in the Thamirabarani river basin. Name of the crops shown in their respective month of commencement.

Because of limitations in land and in supplementary irrigation, Type 3 farmers grew only rice for home consumption and banana as a cash crop. Farmers of Type 4 cultivated less water-demanding crops after harvest of the rice crop using well water. Banana was not cultivated in Type 4 farms due to limited water availability. The variety of crops cultivated in farms of Type 4 included pulses (*Vigna mungo* and *Vigna radiata* (L.) R. Wilczek), oilseeds (*Sesamum orientale* L.), vegetables (*Cucumis anguria* L., *Solanum melongena*, and *Abelmoschus esculentus*), sorghum (*Sorghum bicolor* (L.) Moench), millet (*Pennisetum glaucum* (L.) R. Br.) and cotton (*Gossypium* L. spp.). Pulses were often intercropped with oilseeds and cotton (Figure 4).

The seasonal land use pattern varied across the Farm Types. Farmers of Types 1, 2 and 3 used 75 to 94% of their land in Kharif season whereas Farmers of Type 4 used only 14% of the available land (Figure 5). This was due to water scarcity in these farms since stored water in the rainfed tanks and from wells had been used for the crops cultivated in the previous Summer season.

In the monsoon season Pishanam, Farmers of Types 1, 2 and 3 used almost all the land available for cultivation whereas 30% of the land area was left fallow in Farms of Type 4 due to the anticipated water shortage in the later stage of the crop (rice) growth. In the Summer season, only 10% of the land was used in Farm Type 1 for the perennial crops and to cultivate vegetables, whereas in the farms of the other types, more than 75% of the land was used. Farmers of Type 2 used the Summer season to enrich the soil by cultivating green manure and relay pulse. Farmers of Type 4 cultivated less water demanding cash crops like cotton, pulses, oilseeds and millets in this season as shown in Figure 4.

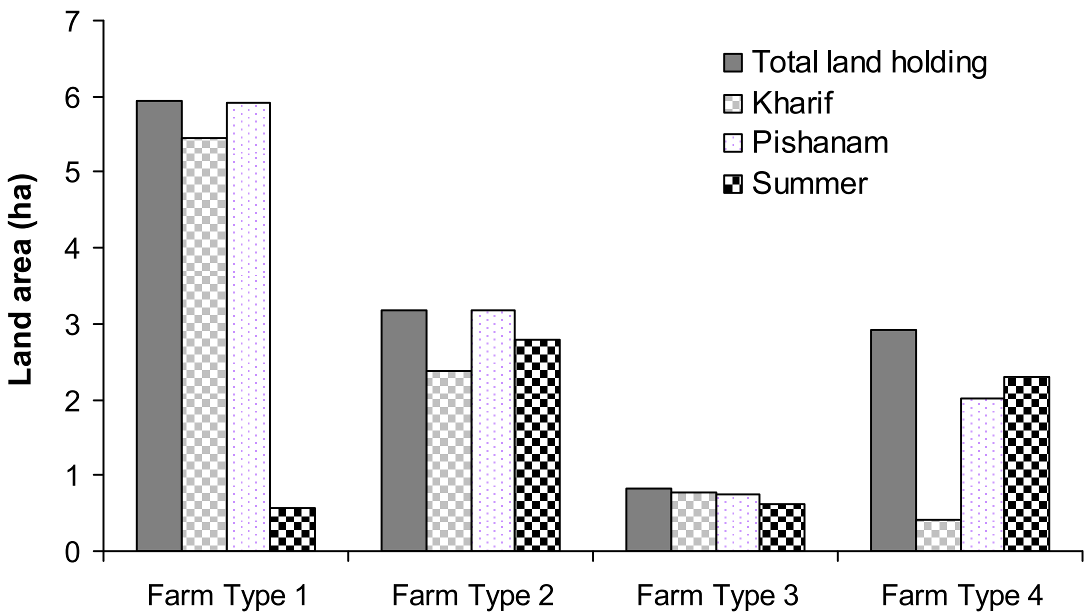

Figure 5. Total land holding and seasonal land use per farm type, quantified during the detailed survey for the three seasons in the year 2005-06.

3.2.2. Income generation through different farm activities by farm types

Farm income was earned through cropping, animal husbandry and off-farm activities in all farm types. The net income including the value of produce consumed by the farm family and animals was highest in Farm Type 1 (US$ 7494 y^{-1}) followed by Farm Type 2 (US$ 4952 y^{-1}). Farm Type 3 and 4 earned less income, i.e. US$ 1212 and 1431 y^{-1}, respectively (Table 2).

The percentage of cash income earned from cropping activities including household consumption was 36%, 46%, 21% and 37% in Farm Types 1, 2, 3 and 4, respectively (Table 2). The value of crop produce consumed within the farm households varied greatly across farm types. It was only 14% in Farm Type 1, more than half (52%) in Farm Type 2 and around 75% in Farm Types 3 and 4. This confirmed increasing dependency on agriculture for food security in the range of Farm Type 1 to 4. Income earned through animals was less than 5% in all farm types. Though in Farm Type 2 a larger number of animals was kept, in comparison with the other farm types the share of income from animals was only 4%. This may be due to the exclusion of non-cash income and intangible benefits obtained by the farm households from the animal activities. Draught power and manure from animals used for cropping activities were not valued in the calculation of income. Importantly, farmers may keep animals not only for income but also for their multifunctional purposes such as insurance, financing and status display (Moll, 2005a; Devendra, 2007). Apart from the income through recurrent products (e.g. milk, manure and draught power) the capital embodied in animals could be substantial: it may constitute 90% of the total assets of the cattle-keeping households as reported for Africa by Moll and Dietvorst, (1999).

Table 2. Income (in US$) earned by farm types through crop, animal and off-farm activities in a year. The mean is based on three farms per farm type and quantified over the period between October 2005 to September 2006.

Farm components	Calculation	Farm Type 1	Farm Type 2	Farm Type 3	Farm Type 4
a) Crop components					
Gross income from crops	a	6216	3496	669	1295
Cost of cultivation on crops	b	3867	1998	523	990
Net income from crops	a-b	2349	1498	146	305
Value of produce used for home consumption + animal feed	c	340	777	110	224
% income used for home consumption + animal feed	(c/g)*100	5	16	9	16
% income from crop	(a-b/g)*100	31	30	12	21
b) Animal components[1]					
Income from animals	d	74	386	63	105
Expenditure on animals	e	28	205	29	27
Net income from animals	d-e	46	181	34	78
% income from animal	(d-e/g)*100	1	4	3	5
c) Off-farm income					
Off-farm income	f	4759	2496	922	824
% income from off-farm	(f/g)*100	63	50	76	58
Total net income including home consumption	g = (a-b)+c+(d-e)+f	7494	4952	1212	1431

[1] Income from animal components was calculated based on the value of the recurrent products (e.g. milk and purchased feed). The embodied production values were not included. The feed provided to the animals from the own farm (e.g. rice straw) and family labour use for animal care were assumed free of cost. Purchase and selling of animals was considered as expenditure and income, respectively.

Surprisingly, income from off-farm activities contributed large shares of earning in all farm types (Table 2). Farmers in Farm Type 1 earned 63% of the farm income through pension and business activities. Since these farmers were highly educated and wealthy, they were able to run a business or received pensions from previous jobs. The off-farm income earned per labour-day (ld) was very high (US$ 35 ld^{-1}) in Farm Type 1, while in other farm types less than US$ 5 ld^{-1} (Figure 6) was earned off-farm. Income through off-farm activities like renting farm machines (e.g. thresher, tractor) and implements (e.g. plough, sprayer) was half of the farm income in Farm Type 2. Farmers of Types 3 and 4 earned off-farm income through selling labour to other farms, working in cities in lean seasons or running a small shop. In Farm Types 3 and 4, mostly the younger generation of the farm family worked outside the farm during most of the year and only returned to the farm during the peak labour demanding periods such as planting and harvesting.

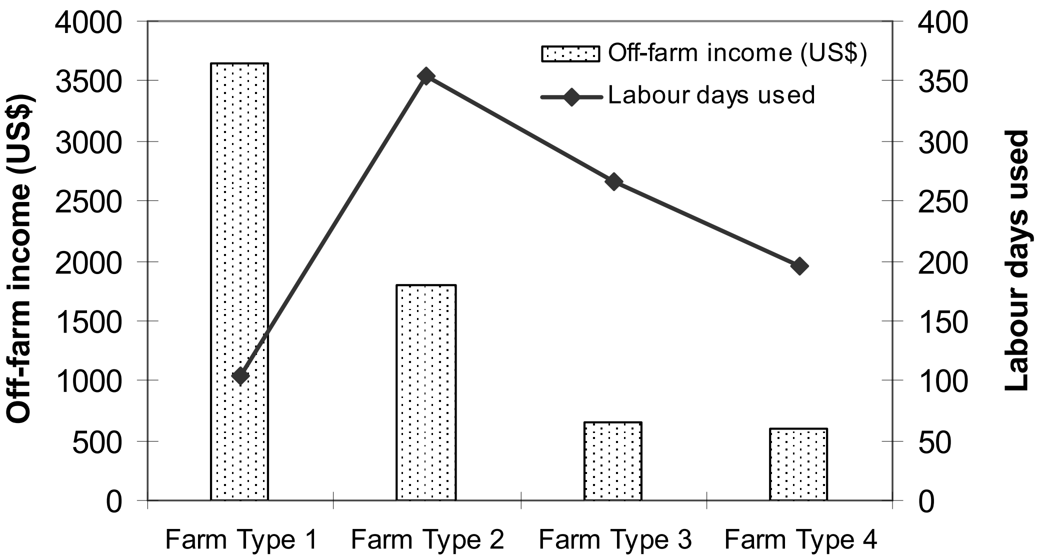

Figure 6. Family labour days used to generate off-farm income in a year in all farm types, quantified in the detailed farm survey in 2005-06.

3.2.3. Input use in the different farm types

Among all farmers, those in Type 2 used higher quantities of seeds per hectare followed by farmers in Type 3, 1 and 4 (Table 3). The cost per kg of seed varied per crop and total seed costs was related to the crops selected for cultivation. Total seed costs were highest in Farm Type 4 (US$ 0.46 kg^{-1}), as in this Farm Type high value crops were cultivated like gherkin (*Cucumis anguria*) (US$ 270 kg^{-1} seed). Organic manure in Farm Types 1, 2 and 3 was obtained from cattle and sheep. Sheep manure was mainly applied through penning, i.e. keeping the sheep herds on agricultural lands overnight prior to last ploughing to ensuring direct dropping of manure and urine on the field). The sheep in herds belonged to both farmers and herdsmen and were moved from field to field. The herdsmen were paid by farmers for taking care of their animals and for the penning of the sheep when they stayed in the farmer's fields over night.

These herds graze on commonly available grazing lands and bring nutrients to the farm, thereby enriching the nutrient balances of the farm land.

Table 3. Operational costs by farm types on seed, manure and fertilizer, agrochemicals, hired labour, and machine & implement use. Mean values is based on three farms per farm type. (Table continued in next page)

Particulars	Farm Type 1 (Average land holding: 5.9 ha)			Farm Type 2 (Average land holding: 3.2 ha)		
	Total amount per farm y^{-1}	Amount ha^{-1} y^{-1}	Cost $unit^{-1}$ in US$	Total amount per farm y^{-1}	Amount ha^{-1} y^{-1}	Cost $unit^{-1}$ in US$
Seed input						
Total seed for sowing (kg)	799	135	0.35	994	311	0.16
Banana suckers (numbers x10^2)	7.4	1.3	2.4	20.7	6.5	4.4
Manure and fertilizer input						
Organic manure (through cattle) (t)	7.4	1.3	11.6	*7.4	2.3	10
Organic manure (through sheep penning) (t)	0.8	0.1	37.5	2.4	0.8	8.4
Organic concentrate (kg)	795	135	0.21	814	254	0.17
Mineral fertilizer kg)	3611	612	0.14	2574	804	0.12
Bio-fertilizer (kg)	38	6.4	0.5	0	0.0	0
Agro-chemical use						
Seed treatment chemicals (kg)	0.5	0.1	2	0	0.0	0
Plant protection-chemicals (liter/kg)	26.4	4.5	7.9	46.5	14.5	2.3
Hired labour use						
Permanent hired labour (Labour days)	371	63	0.8	0	0	0
Hired men labour (Labour days)	165	28	1.7	129	40	1.8
Hired women labour (Labour days)	708	120	1	630	197	0.9
Machine and implement use						
Machine (hrs)	199	33.7	2.4	76	23.8	3.1
Implement (hrs)	164	27.8	0.2	65	20.3	0.3
Rice harvester (hrs)	21	3.6	30.3	9	2.8	31.4
Electric motor (hrs)	255	43.2	0	351	109.7	0
Diesel motor (hrs)	79	13.4	0.8	21	6.6	0.6

* 34.4 t of fresh green manure was incorporated (on 1.4 ha) in addition to the animal manure in one of the farm in Farm Type 2.

Organic concentrates, such as neem and groundnut seed cake and vermicompost were used in all farm types. These concentrates were mixed with urea before application. The quantity of organic concentrate applied in Farm Types 1 and 2 was 135 and 254 kg ha^{-1} y^{-1}, and 28 and 18 kg ha^{-1} y^{-1} in Farm Types 3 and 4, respectively. Mineral fertilizer was used in all Farm Types and the rate of application was high in Farm Types 1, 2 and 3 and comparatively very low in Farm Type 4 (Table 3). Mineral fertilizer application was directly linked to the water availability to irrigate crops. In Farm Types 1, 2 and 3 high quantities of mineral fertilizer were applied since the water availability was not limiting the cropping activities during most of the year. Crops with limited water supply can be supplied with limited quantity of mineral fertilizers

(Wichelns, 2003), explaining the reduced rate of fertilizer application in Farm Type 4 compared with the other farm types.

Table 3 continued..

Particulars	Farm Type 3 (Average land holding: 0.8 ha)			Farm Type 4 (Average landholding: 2.9 ha)		
	Total amount per farm y^{-1}	Amount ha^{-1} y^{-1}	Cost $unit^{-1}$ in US$	Total amount per farm y^{-1}	Amount ha^{-1} y^{-1}	Cost $unit^{-1}$ in US$
Seed input						
Total seed for sowing (kg)	109	136	0.28	262	90	0.46
Banana suckers (numbers x10^2)	6.7	8.4	2.2	0	0.0	0
Manure and fertilizer input						
Organic manure (through cattle) (t)	0.8	1.0	7.4	0	0.0	0
Organic manure (through sheep penning) (t)	2	2.5	5.2	0	0.0	0
Organic concentrate (kg)	22	28	0.11	53	18	0.10
Mineral fertilizer kg)	713	891	0.13	843	291	0.17
Bio-fertilizer (kg)	0	0.0	0	0	0.0	0
Agro-chemical use						
Seed treatment chemicals (kg)	0	0.0	0	0	0.0	0
Plant protection-chemicals (liter/kg)	15.6	19.5	1	8.3	2.9	5.9
Hired labour use						
Permanent hired labour (Labour days)	0	0	0	0	0	0
Hired men labour (Labour days)	69	86	1.6	36	12	2.1
Hired women labour (Labour days)	178	223	0.9	239	82	0.9
Machine and implement use						
Machine (hrs)	27	33.8	4.3	31	10.7	7.6
Implement (hrs)	21	26.3	1	10	3.4	2
Rice harvester (hrs)	1	1.3	28.1	4	1.4	20.4
Electric motor (hrs)	0	0.0	0	148	51.0	0
Diesel motor (hrs)	0	0.0	0	10	3.4	1.1

Bio-fertilizers, e.g. *Azospirillum* and *Phosphobacteria* – despite the doubts as to their efficacy (Giller, 2001) – were applied only in Farm Type 1 (Table 3). Agro-chemicals were used for both seed treatment and crop protection in Farm Type 1, whereas these were only used in crop protection in the other three Farm Types. High quantities of agro-chemicals were used in Farm Type 3 followed by 2, 1 and 4, while the most costly chemicals were used in Farm Type 4 followed by Farm Types 1, 2 and 3 (Table 3). Technologies like bio-fertilizer application and seed treatment with agro-chemicals were linked to the knowledge and education level of the farmers since the adoption of these technologies were observed only in Farm Type 1. Socio-economic conditions, i.e. education and wealth of the farmers may influence the selection of chemicals for plant production. Farmers in Farm Type 1 preferred to use effective chemicals which were priced high in the market while farmers in farm Types 2 and 3 used more and cheaper chemicals (Table 3). Farmers in Farm Type 4 used higher quantities of chemicals to cash crops like gherkin.

Permanently hired labourers were used only in Farm Type 1 with high numbers of temporarily hired men and women labourers. Overall, almost 3 to 8 times more women than men labourers were hired, due to the lower wage rates for women (Table 3). Women labourers were engaged in most labour demanding field operations like sowing, weeding and harvesting while men labourers were engaged in field preparation, fertilizer application and irrigation. Other than field work, men farmers were engaged in off-farm income generating activities as well as procurement of farm inputs and selling of farm produce in the market. The number of hired men and women labour used ha^{-1} y^{-1} was lowest in Farm Type 4 since the available land was not utilized in all three seasons due to water scarcity (Table 3 and Figure 5). In Farm Types 1, 2 and 3, the available land was fully utilized in at least one season and thus labour use was higher. The largest number of hired men and women labour used per ha was found in Farm Type 3 which had a very small land holdings (0.8 ha). Hired labour use decreased further from Farm Type 2 (medium-sized land holding) to Farm Type 1 (largest land holdings). Farm Type 3 may be an example of less labour use efficiency at smaller spatial scales. In general, these small farm systems constitute a large fraction of all farmers (87% of the farm households in Asia) and occupy a predominant position in food production (Devendra, 2007). In the long run, these small farms, however, cannot compete with larger farms in profitability and may ultimately disappear.

The hours of machine and implement used per hectare were almost equal in Farm Type 1 and 3. It was less in Farm Type 2 as the available family labour reduced the need for machines and implements. In Farm Type 4 fewer hours of machine and implement were hired as their cropping activities were limited by water availability. Apart from Farm Type 3, all other types were using electricity and diesel engines to pump water for supplementary irrigation and currently the electricity for agriculture purpose is free of cost in the state.

3.2.4. Family labour use per farm type

Total family labour used was only 98 days y^{-1} in Farm Type 1 (Table 4). Women of the family did not work at the farm; however, they took care of the animals which were kept near the homestead. Family men labour used was high in Summer and Kharif seasons compared with Pishanam; due to the cultivation of vegetables in these seasons (Table 4). Normally, periodic irrigation of rice and banana was done by the permanently hired labourers in Farm Type 1. The family men take over the irrigation work when the permanently hired labourers were engaged in other activities. Family labour requirement for animal care in Summer and Kharif seasons was only 5 days per season compared to 30 days per season in Pishanam (Table 4). The difference was explained by the grazing regime. In Summer and Kharif seasons, all farm animals except milching cows were left with the local herdsman (hired labour instead of family labour) for grazing in the common grazing lands. In the Pishanam season, all animals were kept in the homestead with family labour taking care of the animals.

Table 4. Seasonal family labour use (expressed in labour days of 8 hours) by the four different rice based farm types quantified during the detailed farm survey for three seasons in 2005-06.

Farm Type	Season	*Family labour use in labour days					
		[1]FML for rice irrigation	[2]FML for banana irrigation	FML use excluding 1 and 2	Family women labour	Family men/women labour for animal care	Total family labour use
1	Pishanam, 05	4.1	0	9.5	0	29.8	43.4
	Summer, 05	1.0	0	19.7	0	5.3	26.0
	Kharif, 06	6.9	0	16.4	0	5.0	28.3
	Total	*12.0*	*0*	*45.6*	*0*	*40.1*	*97.7*
2	Pishanam, 05	36.2	0.7	8.9	0	54.9	100.7
	Summer, 05	30.7	4.5	11.3	8.7	62.1	117.3
	Kharif, 06	16.5	20	24.1	18.4	59.5	138.5
	Total	*83.4*	*25.2*	*44.3*	*27.1*	*176.5*	*356.5*
3	Pishanam, 05	2.7	1.3	2.2	0.4	32.9	39.5
	Summer, 05	4.6	4.3	8.4	3.3	34.4	55.0
	Kharif, 06	3.8	1.5	7.3	2.4	34.8	49.8
	Total	*11.1*	*7.1*	*17.9*	*6.1*	*102.1*	*144.3*
4	Pishanam, 05	0	0	17.7	0.9	5.0	23.6
	Summer, 05	0	0	18.1	4.0	5.3	27.4
	Kharif, 06	0	0	11.3	5.5	5.0	21.8
	Total	*0*	*0*	*47.1*	*10.4*	*15.3*	*72.8*

*The time taken for preparation and travel to the site are not included. Family men labour (FML) used for irrigating [1]rice and [2]banana for Farm Types 1, 2 and 3 are presented separately as the real time used for this activity can not be quantified, instead the number of irrigation hours of rice and banana are presented.

Total family labour use was largest in Farm Type 2 (357 days y^{-1}). Women members of the family worked in the fields and also took care of the animals. Periodic operations like irrigating rice and banana were carried out by the family men labour. Most of the family members were engaged in agriculture and family labour use per season was above 100 days in all three seasons. Half of the family labour was spent on animal care (Table 4). Family labour used in Farm Type 3 (144 labour days y^{-1}) consisted of both men and women. Two thirds of the family labour was used for animal care. Total family labour used in Farm Type 4 was 73 days y^{-1}. In these farms, family labourers were used in all three seasons equally for cropping activities. Family women labourers worked in cropped fields and also took care of the animals.

In all four farm types, only the real time used for cropping activities by the family labourers was quantified. The time taken for planning operations, preparation, traveling to fields and to near by cities to purchase inputs was difficult to quantify and not included in the time table. On the other hand, time taken for animal care including cleaning kraals, everyday transport of animal produce (e.g. milk) to local markets was included. The differences in the quantification of family labour used in cropping and animal care biased the data on labour sharing between these two.

3.2.5. Water use from different water resources per farm type

Farmers in Farm Type 1 had access to irrigation water from canals and wells (Table 5). A total of 75,000 m^3 water y^{-1} was used for crop cultivation of which 88% was received from canals and the remaining 12% from wells. In addition, 51,000 m^3 rainfall water y^{-1} was received on the cropped land. The amount of water used in Summer season was only 7% of the yearly total water used from canal and well irrigation sources. The cropped area under rice in Kharif and Pishanam season were almost equal in Farm Type 1 (Figure 5) but the quantity of canal water used was only half in Pishanam season (Table 5). This was due to the monsoon rainfall reducing the irrigation needs from canal in Pishanam season. In Summer, no water from canal was released and cropping activities were restricted to other than rice crops. A small area was under vegetables using well water being only 7% of the yearly water use.

Farmers in Farm Type 2 had access to irrigation water from canals, system tanks and wells. The contribution from wells was much higher (68%) than from canals and system tanks (32%). The water from all irrigation sources were used in all three seasons of the year. In addition to irrigation, cropped land received 25,000 m^3 rainwater y^{-1} (Table 5). This farm type had better control over irrigation water since they were using 68% of irrigation water from privately owned wells. Better control led to the cultivation of a variety of crops like pulses, green manure and vegetables in the Kharif and Summer seasons.

Farmers in Farm Type 3 had only access to irrigation water from canals over which they had little control. They had no wells for supplementary irrigation. Total rainfall received on cropped land was 8,000 m^3 y^{-1} which contributed 50% of the total water used in this farm type. Unavailability of supplementary irrigation from wells and complete dependency on canal water restricted crop choices to only rice and banana. These farmers were not able to grow high value vegetable crops due to lack of water in the Summer season and, in other seasons due to uncontrolled water release which resulted in flooded fields.

The water sources for Farm Type 4 were rainfall, wells and rainfed tanks. The quantity of water used from wells was equal in all three seasons (Table 5). Water for irrigation from rainfed tanks was available only in Pishanam and could be extended to the subsequent Summer season depending on the availability. This controllable irrigation water was only 6000 $m^3 y^{-1}$ equal to 18% of total water available for the entire farm. The remaining 82% (27,000 $m^3 y^{-1}$) was received through rainfall, of which 80% was received in the Pishanam season alone. Farmers in Farm Type 4 were able to cultivate a variety of crops, however, though limited by available water from wells and rainfed tanks. Cultivation of rice for home consumption in the Pishanam season was possible because of the intensive monsoon rainfall. Crops like vegetables can not be cultivated in this season as it cannot withstand water logging even for a short period of 3-5 days (Belford et al., 1980; Matta and Garibaldi, 1980). Water from wells and commonly available rainfed tanks was used to complete the rice crop in the later stage of the Pishanam season.

Table 5. Seasonal water use from different water sources by the four different rice based farm types quantified through detailed farm survey during the year 2005-06.

Farm Type	Season	Water use from irrigation sources (10^3 x m^3)				Rainfall	
		Canal	System tank	Well	Rainfed tank	10^3 x m^3	mm
1	Pishanam, 05	20.6	0	2.4	0	36.6	617
	Summer, 05	4.0	0	1.0	0	6.8	114
	Kharif, 06	41.5	0	5.6	0	7.1	119
	Total	*66.1*	*0.0*	*9.0*	*0.0*	*50.5*	*850*
2	Pishanam, 05	0.8	5.4	15.4	0	15.0	469
	Summer, 05	5.7	0.9	8.6	0	6.5	204
	Kharif, 06	2.3	1.0	10.9	0	3.5	111
	Total	*8.8*	*7.3*	*34.9*	*0.0*	*25.0*	*784*
3	Pishanam, 05	1.5	0	0	0	4.9	627
	Summer, 05	4.4	0	0	0	2.2	277
	Kharif, 06	2.0	0	0	0	0.7	83
	Total	*7.9*	*0.0*	*0.0*	*0.0*	*7.8*	*987*
4	Pishanam, 05	0	0	1.3	1.6	21.9	748
	Summer, 05	0	0	1.6	0.1	4.6	158
	Kharif, 06	0	0	1.3	0	0.9	32
	Total	*0*	*0*	*4.2*	*1.7*	*27.4*	*938*

3.3. Opportunities and constraints to adopt modified rice cultivation

The socio-economic and bio-physical characteristics of the four farm types were distinct. Opportunities and constraints of the farm types to adopt modified rice cultivation are described in Table 6. The adoption possibilities of the four major techniques of this modified rice cultivation being water-saving irrigation, modified planting, mechanical weeding and organic manure application, are discussed with respect to the current structure and functioning of all four farm types.

3.3.1. Water-saving irrigation

Although water-saving irrigation was found to increase rice yield in China (Mao, 1993; Wu, 1999; Li, 2001), it was not observed with water-saving irrigations in Tamil Nadu (Thiyagarajan et al., 2002; Thiyagarajan et al., 2003; Senthilkumar et al., 2008). In general, however, adoption of water-saving irrigation did not effectively harm the livelihood of the farmers in all farm types. Improving water productivity in rice through the adoption of water-saving irrigation is, nevertheless, important to alleviate the water scarcity problem at the regional scale. To this end actions are needed to be taken at the farm scale. In Farm Type 1, nearly 88% of the irrigation water was received from canals to irrigate both Kharif and Pishanam rice. Farmers in this farm type had no control over irrigation water. There were no incentives for farmers to adopt water-saving irrigation as both water from reservoirs and electricity for pumping well-water were free of cost (Senthilkumar et al., 2008). Creating awareness on water scarcity at regional level may have an effect on the adoption of water-saving irrigation. Given the higher education level of the farmers in Farm Type 1 (Table 1), this may be effective in this farm type. However, farmers in Farm Type 1 were not engaged themselves in irrigation. It was often done by the permanently hired labourers (Table 3), which implies that training and awareness on water-saving irrigation should be given not only to the farmers but also to the permanently hired labourers. Farmers in Farm Type 2 had better control over the irrigation water as they were using 68% of irrigation water from wells (Table 5). Creating awareness on water-saving irrigation may affect the adoption rate in this farm type. However, the electricity for pumping water is free of cost to the farmers leading to low incentives for adoption. Farm Type 3 had little control over irrigation whereas controllable irrigation from wells was not available (Table 5). Also these farmers have no incentives to save irrigation water. In Farm Type 4, farmers rely solely on rainfall during the initial phase of the monsoon season Pishanam. During the later phase of rice growth water-saving irrigation is an option using water from wells and stored water from rainfed tanks. However, rice yield was reduced if water-saving irrigation was applied after flowering stage of the crop (Thiyagarajan et al., 2002). In non-monsoon seasons, farmers of Farm Type 4 chose a number of other less-water demanding crop rather than rice.

Table 6. Opportunities and constraints influencing the adoption of techniques in modified rice cultivation for different farm types.

Factors	Farm Type 1	Farm Type 2	Farm Type 3	Farm Type 4
a) General farm characteristics and endowments				
Land use[1]	Full	Full	Full	Partial
Possible constraints on land use	Labour	Labour	Labour and investment	Water, labour and investment
Family labour use	Very low	Very high	Under utilized due to land constraint	Under utilized due to water constraint
Dependency on hired labour for cultivation	Very high	High	Medium	Medium
Water availability	Very high	Very High	High	Limited
Farmer's control over water resources[2]	Low	Medium	Low	High
Dependency on external water resources[2]	High	High	Very high	Low
Vulnerability to water stress during the growing season	Low	Low	Very high	Always
Possibilities for diversified cropping	Low	Medium	Low	High
Investment capacity of the farm	Very high	High	Low	Low
b) Adoption possibilities of techniques in modified rice cultivation				
Water-saving irrigation	Very low	Low	Very low	Not applicable
Modified planting	Medium	Medium	High	High
Mechanical weeding	High	High	High	High
Organic manure application	High	Very High	High	Very low

[1]Minimum for a season; [2]Water resources excluding rainfall

3.3.2. Modified planting

Planting younger seedlings with wider spacing in a square pattern had significantly increased the grain yield and reduced the seed requirement (Uphoff, 1999; Stoop et al., 2002; Thiyagarajan et al., 2002; Uphoff, 2002; Thiyagarajan et al., 2003; Senthilkumar et al., 2008). Opportunities exist in all four farm types to adopt the modified planting method, however, the constraints varied across farm types. In order to plant young seedlings, dapog nursery beds need to be developed (Uphoff, 2002; Thiyagarajan et al., 2003). In the Philippines a nursery method is developed, where seedlings are raised on an artificial surface, like a polythene sheet, to easily transport plants to the field and to transplant at a younger age. In Farm Types 1 and 2, more than 90% of the land was used for rice cultivation both in Kharif and Pishanam season. The average land holding was 7 and 4 hectare in Farm Types 1 and 2, respectively (Table 1). A relatively large area needs to be planted in a short period of one to two weeks just after the release of the canal water. Modified planting required 50% more women labourers than conventional planting and women labourers expressed unwillingness for modified planting (Senthilkumar et al., 2008). Higher labour demand in a short period of one to two weeks to plant the whole farm area may hinder adoption of modified planting in Farm Types 1 and 2. Furthermore, to maintain planting age of seedling below 15 days, staggered sowing is required. Keeping the dapog nursery seedlings beyond 20 days leads to intertwining of the roots making the seedlings unfit for planting (Senthilkumar et al., 2008). Modified planting can be a better option in Farm Types 3 and 4. The land area under rice cultivation was less than a hectare and family labourers themselves as well as labour from neighbouring farms were engaged in planting operation through labour exchange.

3.3.3. Mechanical weeding

Mechanical weeding using a rotary or cono weeder significantly increased the grain yield over the conventional hand weeding (Dinesh and Manna, 1990; Thiyagarajan et al., 2002; Thiyagarajan et al., 2003; Senthilkumar et al., 2008). Practicing modified planting, i.e. square planting with wider spacing, is a prerequisite for the adoption of mechanical weeding in all farm types in order to allow the rotary or cono weeder to operate in between the plant rows in both directions. It is obvious that, the farms who can adopt modified planting can adopt mechanical weeding as well. The possible constraint in adoption is the shift from women labour to men labour. Traditionally, hand weeding in rice was carried out by the women labourers. Introduction of mechanical weeding led to a shift from the use of women labour for hand weeding to men labour for mechanical weeding (Senthilkumar et al., 2008). This shift in gender leads to job loss to women and more jobs for men labourers but at higher costs since labour wages of men are higher than for women. Overall almost 3 to 8 times more women than men labourers were hired, due to the cheap wage rates for women (Table

3) in all four farm types. A drastic shift in labour gender is required for the adoption of mechanical weeding in Farm Type 1 and 2, but less so in Farm Type 3 and 4 as the family men labour can do the mechanical weeding, alone or jointly with the neighbouring small farmers.

Adoption of modified planting and mechanical weeding depends on the type of labour used; i.e. family or hired labourers. Hired labour, more used in Farm Types 1 and 2 (Table 3), complained of difficulties with modified planting and mechanical weeding (Senthilkumar et al., 2008). Family labour complained less of modified planting and mechanical weeding. In Farm Type 3 and 4, planting and weeding operations in rice were carried out by family labourers either from the own farm or by labour exchange with neighbouring farms. Adoption of modified planting and weeding thus may be possible in Farm Types 3 and 4 if farmers receive training on these techniques.

3.3.4. Organic manure application

Organic manure application to rice depended on the manure availability within the farm and the ability of farmers to procure from outside. Organic manure used from cattle and sheep penning was 1.4, 3.1 and 3.5 t ha^{-1} in Farm Types 1, 2 and 3, respectively; it was not used in Farm Type 4 (Table 3). The recommended level of organic manure application in the modified rice cultivation was 6.25 t ha^{-1} either as animal manure or green manure along with the recommended mineral fertilizer of N (150 kg ha^{-1}), P (26 kg ha^{-1}) and K (75 kg ha^{-1}) (Thiyagarajan et al., 2002; Thiyagarajan et al., 2003; Senthilkumar et al., 2008). Application of organic manure is possible in Farm Types 1, 2 and 3, but rates did not match the recommended level because of the short supply. Farmers in Farm Type 2 had more organic manure available as they were maintaining higher number of animals than farmers in other farm types (Table 1). They also cultivated green manure (Figure 4). Farm Type 4 cannot apply organic manure in rice cultivation as they did not have access to animal manure nor cultivated green manure.

4. Conclusions

Typifying farms into farm types helped to understand the structure and functioning of rice based farming systems in the state of Tamil Nadu. Farm characteristics of the four distinct farm types varied greatly in income, water and labour use, input use and livelihood dependency on farming. Opportunities exist to adopt one or more technologies of the modified rice cultivation in all four farm types. Uphoff, (2001) reported that rice yield increased with increasing number of adopted techniques. Thus, constraints limiting the adoption of each of the four techniques in modified rice cultivation need to be taken into account. For example, improving the irrigation infrastructure, for example by cementing the irrigation channels, and creating more control over the irrigation water to the farmers would provide an opportunity for farmers in Farm Types 1, 2 and 3 to adopt the water-saving irrigation not in Farm Type 4. Adoption depends on farmers' willingness to change, which in turn depends on their concern and awareness on the need to use irrigation water efficiently. Incentives to do so are lacking as water and electricity for pumping is free of cost at present.

In all four farm types, however, the opportunity to adopting the water-saving irrigation was found to be the least promising. In general, adoption of water-saving irrigation will not effectively improve, but also not harm the farmers' livelihood. To solve the water scarcity problems at regional scale is important but only can be realised through changing farmers practices. Effective government policies in different policy domains such as rules and regulations, pricing, institution building and infrastructure development, training and education to the farmers are needed to improve the adoption of modified rice cultivation, including water saving. Policy measures will affect farms in the different categories differentially. At regional level pricing of water and electricity may stimulate water saving. Large farms (Farm Types 1 and 2 with land holdings > 2 ha) will be stimulated to do this which will be effective at regional level. Although these farmers make up only 10% of the farming community in the state, they use the major portion of the irrigation water. The small farms (Farm Types 3 and 4) with < 2 ha that either use or do not use irrigation water from canals constitute 90% of the farming community in the state. They use, however, a minor proportion of the irrigation water. Their livelihoods will be affected negatively and reduction in water use at state level will negligible. The state also should take care to sustain present food self sufficiency and to meet future food requirements. Rice productivity needs to increase by at least 3% annually (Thiyagarajan and Selvaraju, 2001). Increasing rice production with less water through adoption of water-saving cultivation is an imperative given the water scarcity but so also to sustain food security.

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Chapter 4

Impact of policies on farm households varying in resource endowments and use efficiencies: which policy instruments to select?[†]

[†] Adapted from:
Senthilkumar, K., Bindraban, P.S., de Ridder, N., Thiyagarajan, T.M., Giller, K.E., 2008. Impact of policies on farm households varying in resource endowments and use efficiencies: which policy instruments to select? Land Use Policy. Submitted.

Abstract

Livelihoods of rice farmers depend on the efficient use of agricultural resources that are available in scarce quantities. Farmers tend to maximize economic output of farming activities which may not necessarily coincide with the optimal use of resources from an ecological perspective. However, improving resource use efficiencies at the regional level is important for society at large. Efficiencies can be enhanced by well-chosen combinations of resource efficient technologies at the farm level and policy interventions at the regional level, thereby obtaining a balance between the objectives of both farmers and society. Rice-based farms in Tamil Nadu, India, were grouped into four farm types based on their biophysical and socio-economic characteristics. Crop and farm level resource use efficiencies of water, labour, capital and nutrients were quantified in three representative farms per farm type. The four farm types differed in water, labour and nutrient productivity and profitability both at crop and farm level. Water productivity was poor in Farm Types 1, 2 and 3 compared with Farm Type 4 due to the open access to the commonly available canal water of the first types. Labour productivity was highest in Farm Type 2 due to more family labour use and least in Farm Type 3 due to the small operational holding. Farm Types 1 and 2 were most profitable and Farm Types 3 and 4 were least profitable – directly related to the resource endowments. Farm Type 3 was least efficient in all the resources considered, emphasizing the negative effect of low resource endowments. Possible policy interventions in order to improve the resource use efficiencies and their effect on the farmer livelihoods are discussed. Government policy interventions may influence the farm resource use efficiencies through the adoption of resource efficient technologies. However, an identical set of policy interventions cannot be applicable to all farm types since current resource use efficiencies and adaptability of these farm types for change in policies differed substantially. Comprehensive analytical tools need to be developed to study the effect of different combinations of policy interventions on enhancing resource use efficiencies without harming the livelihoods of the farmers.

Keywords: Farm typology; Water productivity; Labour productivity; Profitability; Nutrient productivity; Partial nutrient balance; Farmer livelihoods.

1. Introduction

Farmer livelihoods rely on a basket of assets such as human, natural, physical, financial and social capital (Chambers, 1991; Sen, 1997; Moser, 1998; Bebbington, 1999). The livelihood of most farmers in the state of Tamil Nadu, India depends on limited available agricultural resources. Uncontrolled (open) access to these resources like water, leads to inefficient use due to inappropriate management practices. Farmers tend to maximize economic output from their farming activities which may not necessarily coincide with the optimal use of resources from an ecological perspective (Senthilkumar et al., 2008). In order to optimize the resource use efficiencies without harming farmer livelihoods, quantitative insight on the relations between economic behavior of the farmers and ecological implication of the resource use is required to identify optimal strategies to sustain the agricultural production system.

Government interventions on the use of commonly available agricultural resources can have significant effects on the incentives and opportunities available to farmers in making choices on resource use. Improving water use efficiency (WUE) and nutrient use efficiency (NUE), i.e. reducing the nutrient losses and pollution of an entire region is important for irrigation engineers and policy makers. However, improving WUE may not be a major concern for farmers who have open access to irrigation water that is available free of cost. Improving NUE to reduce pollution may also not be a driving force as it brings no direct benefits to the farmers. Farmers may, on the other hand, be willing to increase NUE to enhance yield and minimize costs of labour and capital. It is, therefore, important to link the objectives at the farm level to those at the regional level in order to identify intervention measures for improving the livelihood of farm households while meeting regional targets. Trade-offs in achieving the objectives of the two operational levels should be minimized while maximum synergy has to be looked for.

The efficiency and sustainability of agricultural production systems can be enhanced by well-chosen combinations of policy interventions (Kuyvenhoven, 2004). A policy may be characterised as a consistent set of objectives, instruments for achieving those objectives, and rules for operating the instruments (Colman and Young, 1989). Agricultural policy instruments are classified based on the level of imposition, i.e. (1) directly at farm level, (2) at the national frontier, or (3) at some other point in the domestic market (Colman and Young, 1989). The policy instruments imposed at the farm level can comprise deficiency payments, production and input subsidies/credit, investment grants, production or acreage quotas, compulsory food requisition and land reform measures. At the frontier and market level, pricing and taxation, intervention by buying products and food subsidies, and public investment on education, research, and infrastructure are the main policy instruments (Colman and Young, 1989).

As farms are unique in their resource endowments and characteristics, differences can be expected in resource use efficiencies (RUEs) based on the current structure and functioning of farms. Regional level resource use efficiencies are the cumulative effect of individual farm resource use efficiencies, thus government policy needs to stimulate improvement of RUEs at the farm level. However, policy instruments will affect individual farmer decisions and their livelihood differently depending on farmer objectives, farm structure and functioning. Therefore, current RUEs of farms have to be quantified and understood before the effects of different policy instruments on improving the RUEs and farmer livelihoods can be explored.

Rice (*Oryza sativa* L.) is one of the most important crops of the farmers in Tamil Nadu, which has low water use efficiency while the availability of water at regional level is becoming scarce. On-station and on-farm experiments were carried out on modified rice cultivation including water saving techniques compared with conventional rice cultivation techniques. Overall, water saving of 40-50% without reduction in yield were found with modified rice cultivation, resulting in an increase in water productivity of 40-47% over conventional rice cultivation (Thiyagarajan et al., 2002; Senthilkumar et al., 2008). These modified rice cultivation techniques were, however, hardly adopted by the farmers, because of technical difficulties in the novel cultivation practices, labour constraints and gender issues (Senthilkumar et al., 2008). Still, it is important to improve water use efficiency at regional level. Insights are required as to how and to what extent changes at policy level (e.g. water pricing policies at state level) may create incentives to farmers and influence adoption at farm level (e.g. of water-saving techniques) leading to savings in resources.

The objectives of this study were: 1) to estimate the current resource use efficiencies of land, water, nutrients, labour and capital in rice-based farming systems of different cropping activities; 2) to describe the differences in resource use efficiencies across farms using economic and environmental indicators; and 3) to discuss the potential impact of change in policies using different instruments to improving resource use efficiencies and farmer livelihoods.

2. Materials and methods

Four different rice-based farm types were identified based on biophysical and socio-economic conditions in Thamirabarani river basin, Tamil Nadu, India (Senthilkumar et al., submitted-a). The important farm characteristics (e.g. income) and resource endowments (e.g. water and labour availability) of the four rice-based farm types are presented in Table 1.

An in-depth farm survey was conducted across the four rice-based farm types by sampling 3 farms per farm type for four consecutive cropping seasons (16 months) from June 2005 to September 2006. Farms were surveyed weekly and water, labour, capital and nutrient allocation were monitored for each cropping activity.

Table 1. Resource endowments and characteristics of four farm types. Data are per farm per year, averaged over three sample farms, based on Senthilkumar et al., (submitted-a).

Farm resource endowments and characteristics	Farm Type 1	Farm Type 2	Farm Type 3	Farm Type 4
Land available (ha)	5.9	3.2	0.8	2.9
Family labour use (Labour days)	98	357	144	73
Hired labour use (Labour days)	1,244	759	247	275
Water use (10^3 x m^3)				
Canal	66.1	8.8	7.9	0.0
System tank	0.0	7.3	0.0	0.0
Well	9.0	34.9	0.0	4.2
Rainfed tank	0.0	0.0	0.0	0.1
Rainfall	50.5	25.0	7.8	27.4
Farm net income (US$)				
Crops	2,349	1,498	146	305
Animals	46	181	34	78
Off-farm	4759	2496	922	824

Water used for each cropping activity from canals and system tanks (fed by canals and that can provide irrigation water for a longer period than canals) were measured by using Parshall flumes. Water use from wells was estimated from the discharge rate of the electric or diesel motor and the duration of pumping. Rainfall was measured by placing a rain gauge at each farm. Hired and family labour use per cropping activity was quantified and expressed in labour days of 8 hours. Family labour used for irrigating rice and banana were estimated as 10% of the actual duration of irrigation, since farmers only need to open and close the inlets of the channels for irrigation. For other crops like vegetables and pulses, the total duration of irrigation hours were considered as labour use hours, since the farmers need to engage in diverting water for the entire duration of irrigation. Capital inflow through application of agricultural inputs like seed, fertilizer, hiring labour and machinery were quantified per cropping activity. N, P and K input per cropping activity was derived from the application rate of chemical and organic fertilizers.

Animal components were not considered in this study since their contribution to the farm income was less than 5% of the total income in all four farm types (Senthilkumar et al., submitted-a). However, animal draught power for cropping activities was valued as free of cost.

2.1. Quantifying resource use efficiencies

Water and labour productivity, profitability of capital use and productivity of N, P and K along with nutrient balances were used as indicators to identify use efficiencies of resources at both crop and farm level. Calculations at crop level were expressed on a hectare basis and the average values per cropping activity were multiplied by the area (weighted) to aggregate to the farm level. Failed and standing crops were excluded from the calculations of resource use efficiencies at the crop level, but were included at the farm level, since calculations were for a period of 16 months. Crop yield expressed on dry weight basis, and income earned per unit resource use were used to express the resource use efficiencies in biophysical and economic terms, respectively (see Table 2 for equations).

Table 2. Equations used to calculate the indicators of the resource use efficiencies in bio-physical and economic terms in all farm types.

Indicator	Level of estimation	Equations	Unit
Biophysical term			
Water productivity^{Y}	Crop & Farm	Y_{dw} / (Wi + Wr)	kg m^{-3}
Labour productivity^{Y}	Farm	Y_{dw} / total labour hrs	kg hr^{-1} labour
Profitability^{Y}	Farm	Y_{dw} / $ input	kg $\$^{-1}$
N productivity^{Y}	Farm	Y_{dw} / N input	kg kg^{-1}N
P productivity^{Y}	Farm	Y_{dw} / P input	kg kg^{-1}P
K productivity^{Y}	Farm	Y_{dw} / K input	kg kg^{-1}K
Economic term			
Water productivity$^{\$}$	Farm	Income / (Wi + Wr)	$ m^{-3}
Labour productivity$^{\$}$	Farm	Income / total labour hrs	$ hr^{-1} labour
Labour productivity$^{\$(total)}$ (LP^{a})	Crop	Income / $ input on total labour	$ $\$^{-1}$
Labour productivity$^{\$(hired)}$ (LP^{b})	Crop	Income / $ input on hired labour	$ $\$^{-1}$
Profitability$^{\$}$	Crop & Farm	(Income / $ input) - 1	$ $\$^{-1}$
N productivity$^{\$}$	Farm	Income / N input	$ kg^{-1}N
P productivity$^{\$}$	Farm	Income / P input	$ kg^{-1}P
K productivity$^{\$}$	Farm	Income / K input	$ kg^{-1}K

^{Y} = Resource use efficiencies calculated using crop yield; $^{\$}$ = Resource use efficiencies calculated using income; Y_{dw} = Yield (kg dry weight ha^{-1}); Wi = Water applied through irrigation (m^3); Wr = Water received through rainfall (m^3); Income = Produce sold in the market + produce consumed within the farm, valued for market price; $ input = Cost of seed, fertilizer, manure, agro-chemicals, labour, hiring machines and implements. Conversion to US$ at a rate of Rs. 45 per US$.

Farm level labour productivity was calculated for the total labour use, i.e. including permanently and temporarily hired labour, and family labour. Labour productivity at the crop level was calculated in two ways, (1) total labour use assuming wage rates for family labour similar to hired labour, and (2) hired labour use assuming family labour as free of cost (Table 2).

Water from canals and system tanks, and electricity to pump well water using electric motor were both free of cost to the farmers. However, when a diesel motor was used, hiring and fuel costs were included. The quantity of seed, amount of manure and the use of machines and implements from the own farm were valued free of cost, while operational costs of purchased inputs and hiring cost of machines and implements were included as costs.

2.2. Quantifying partial nutrient balances

Partial nutrient balances were calculated for the major nutrients N, P and K at both crop and farm level. Partial nutrient balances include only the flows that are visible to the farmers and can be measured and managed by farmers (Defoer et al., 1998). Other nutrient inflows like biological nitrogen fixation by legumes, sedimentation by run on, wet deposition, and mineralization and nutrient outflows through volatilization or denitrification, leaching, run off and erosion were not included. These flows are difficult to measure and often estimated using transfer functions. Although they may contribute importantly to a complete balance, they were not included because measurements are lacking and transfer functions from elsewhere may not be valid for the region under study. Nutrient inflows considered were chemical fertilizers (IN_1), organic manure from cattle (IN_2), organic manure from sheep penning (IN_3), organic concentrates (e.g. neem and groundnut cake) (IN_4), green manure (IN_5) and seed input (IN_6). Nutrient outflows were the main crop produce (e.g. grain, fruit, flower and tuber; OUT_1) and crop residues removed from the field (e.g. straw, stover; OUT_2). Nutrient content of crop components obtained from literature were used for the balance calculations (Table 3). The nutrient concentration in a crop and its components may vary greatly due to differences in soil fertility and abilities of crops to take up nutrients relative to the water availability. Because the application rates of the nutrients to crops in the study area were in the medium range for most crops as prescribed by the state agricultural department, we used the mean values of plant nutrient contents found in literature. The nutrient content of chemical fertilizers, organic manure and organic concentrates are presented in Table 4. The equations to calculate the partial nutrient balance at crop and farm level are presented below.

$$PNB\_crop = \sum_{i=1}^{I} INFLOW - \sum_{i=1}^{O} OUTFLOW$$

Where,

PNB_crop = crop level partial nutrient balance (kg ha^{-1}),
I = number of inflows,
O = number of outflows.

$$PNB\_farm = \frac{\sum_{j=1}^{n}(PNB\_crop_j \times X_j)}{\sum_{j=1}^{n} X_j}$$

Where,

PNB_farm = farm level partial nutrient balance (kg farm^{-1}),
PNB_crop_j = crop level partial nutrient balance of crop j (kg ha^{-1}),
n = number of cropping activities,
Xj = actual land area of cropping activity j.

Table 3. Nutrient content of crops on dry weight basis used for nutrient balance estimation of difference farm types of rice-based farming system in research area.

Crops	N %		P %		K %		Reference
	MP	BP	MP	BP	MP	BP	
Banana	1.05	1.05	0.13	0.12	3.05	5.05	(Nijhof, 1987a)
Beetroot	2.10	0	0.32	0	2.45	0	USDA
Black gram	4.30	0	0.40	0	1.30	0	(Brink and Belay, 2006)
Coconut	0.83	0	0.07	0	0.95	0	(Nijhof, 1987a)
Cotton	1.90	1.50	0.50	0.36	1.45	1.35	(Nijhof, 1987b)
Cowpea	3.80	1.73	0.40	0.19	1.35	2.28	(Nijhof, 1987b)
Egg plant	2.13	3.04	0.22	0.35	3.00	0	(Prabhu, 2001), USDA
Finger millet	2.33	0.66	0.46	0.37	0.35	2.25	(Nijhof, 1987b)
Fodder Lablab	3.80	1.73	0.40	0.19	1.35	2.28	(Nijhof, 1987b)
Fodder Sorghum	2.10	0.78	0.39	0.18	0.48	1.80	(Nijhof, 1987b)
Gherkin* (Cucumber)	0.10	0	0.02	0	0.15	0	(Herrero et al., 2007)
Green gram	4.10	0	0.40	0	1.30	0	(Brink and Belay, 2006)
Green manure*	0.93	0	0.09	0	0.78	0	(Sudhalakshmi, 2002)
Jasmine*	1.34	0	0.16	0	1.72	0	(Senthamizhselvi, 2000)
Ladies finger	2.45	1.45	0.45	0.17	2.55	2.25	(Nijhof, 1987b)
Lemon	0.95	0	0.15	0	0.87	0	USDA
Mulberry*	0.54	0	0.08	0	0.03	0	(Setua et al., 2005)
Onion	1.95	2.40	0.68	0.67	1.25	2.80	(Nijhof, 1987b)
Pearl millet	2.08	0.70	0.53	0.20	0.55	1.70	(Nijhof, 1987b)
Rice	1.85	1.05	0.35	0.12	0.52	1.73	(Nijhof, 1987b)
Rose*	1.76	0	0.28	0	1.80	0	(Lorenzo et al., 2000)
Sesame	1.85	1.05	0.30	0.54	1.50	1.80	(Nijhof, 1987b)
Sorghum	2.10	0.78	0.39	0.18	0.48	1.80	(Nijhof, 1987b)
Tomato	2.60	2.20	0.53	0.46	3.75	3.65	(Nijhof, 1987b)
Tuber (Potato)	1.70	2.30	0.35	0.57	2.85	2.73	(Nijhof, 1987b)
Turmeric	0.77	0	0.15	0	0.83	0	(Velmurugan, 2002)
Yam	2.34	0	0.24	0	2.67	0	(Sharmila, 2001)

* Nutrient content on fresh weight basis; MP = Main product of crop (e.g. seed/grain, fruit, flower, tuber), BP= Byproduct of crop (e.g. straw, stover); USDA = Data from the website http://npk.nrcs.usda.gov/

Table 4. Nutrient content of chemical fertilizers, organic manure and organic concentrates used for nutrient balance estimation.

Fertilizers	N%	P%	K%	Reference
Chemical fertilizers				
Urea	46	0	0	(Tisdale et al., 1993)
Ammonium chloride	25	0	0	″
Ammonium sulphate	21	0	0	″
Di Ammonium Phosphate (DAP)	18	20	0	″
Single Super Phosphate (SSP)	0	7	0	″
Murate of Potash (MoP)	0	0	50	″
Complex fertilizer – Type 1	17	7	14	Farm survey
Complex fertilizer – Type 2	16	0	10	″
Complex fertilizer – Type 3	10	13	24	″
Complex fertilizer – Factamfos	20	9	0	″
Organic manure				
Cattle manure	0.50	0.13	0.75	(Gaur et al., 1990)
Sheep penning				
a) Dung	0.65	0.22	0.02	″
b) Urine	1.70	0.01	0.21	″
Organic concentrates				
Vermicompost	1.72	1.27	1.14	(Pramanik et al., 2007)
Neem seed cake	4.00	3.00	0.46	www.lkfarmpro.com/neemcake.html
Groundnut seed cake	7.29	0.73	1.10	www.fao.org
Horn meal	1.20	0.70	0.20	(Powers and Van Horn, 2001)

2.3. Selection of policy instruments

Though there are many policy instruments that can be introduced at farm and frontier level, the following instruments are found to be useful in enhancing resource use efficiencies, they are: 1) pricing and taxation; 2) rules and regulations (e.g. acreage quotas); 3) investment on education, training and infrastructure development; and 4) institution building and organized co-operative management. The potential effects of these policy instruments on enhancing resource use efficiencies and farmers livelihoods are discussed.

3. Results and discussion

3.1. Resource use efficiencies of crops

Crop activities were defined by the season of cultivation (e.g. Kharif rice), source of irrigation and similarity in crop management practices (Table 5). The use efficiencies

Table 5. Water use (10^3 x m^3 ha^{-1}) and water productivity (kg DM yield m^{-3}) of crops cultivated in different farm types in the Thamirabarani river basin, Tamil Nadu.

Crops	Farm Type 1		Farm Type 2		Farm Type 3		Farm Type 4	
	Water use	Water productivity	Water use	Water productivity	Water use	Water productivity	Water use	Water productivity
Kharif rice	9.2	0.39	14.4	0.31	8.3	0.51	-	-
Kharif rice (WI)	27.3	0.04	-	-	-	-	-	-
Pishanam rice	11.3	0.30	14.5	0.38	9.3	0.37	8.7	0.51
Pishanam rice (WI)	10.3	0.17	-	-	-	-	-	-
Banana	26.9	0.17	30.2	0.13	28.5	0.18	-	-
Banana (WI)	29.1	0.32	-	-	-	-	-	-
Perennials[1]	14.3	0.01	-	-	-	-	-	-
Green manure	-	-	8.8	0.00	-	-	-	-
Relay pulse	-	-	1.8	0.05	-	-	-	-
Vegetables[2]	14.2	0.07	-	-	-	-	6.3	0.12
Pulses[3]	-	-	3.1	0.16	-	-	5.4	0.11
Millets[4]	-	-	-	-	-	-	6.3	0.24
Oilseeds[5]	-	-	-	-	-	-	1.1	0.12
Mixed crops[6]	-	-	-	-	-	-	1.9	0.12
Fodder crops[7]	-	-	-	-	-	-	4.9	0.49

[1] Jasmine and Rose; [2] Okra, Egg plant, Tomato, Gherkin and Onion; [3] Green gram, Black gram and Cowpea; [4] Sorghum, Pearl millet and Finger millet; [5] Sesame; [6] Cotton + Pulses and Oilseeds + Pulses; [7] Fodder sorghum and Fodder cowpea; WI = Well irrigated upland crop; 000 m^3 = 1 million liters.

for water, labour, capital and nutrients for different crop types were analysed within each farm type and across the four different farm types.

3.1.1. Water use and water productivity

On the farms of Type 1, large differences in water productivity were observed between lowland and upland rice and between water sources used. Highest water productivity of 0.39 kg m^{-3} was obtained in Kharif rice followed by Pishanam rice with a water productivity of 0.3 kg m^{-3} (Table 5). The difference is likely due to the intensive monsoon rain in Pishanam season leading to a slightly higher water use of the rice crop (11,300 m^3) than during the Kharif season (9,200 m^3). Lower water productivities of 0.04 and 0.17 kg m^{-3} were observed for upland rice cultivated with well water in the Kharif and Pishanam seasons, respectively. The extremely low water productivity for the well irrigated Kharif rice was explained by poor yields and large volume of irrigation water used (27,300 m^3). Farmers applied much water to suppress the high weed infestation observed in this crop and the low yields obtained despite the engagement of more labourers for weeding. The practice of flooding rice fields to suppress weed infestation was reported earlier (De Datta, 1981; Bouman and Tuong, 2001; Warner et al., 2006). The grain yield was 1 to 1.5 t ha^{-1} in upland rice while it was 3.4 to 3.6 t ha^{-1} in lowland rice (Table 6). The area under upland rice was, however, less than one hectare in both seasons and did not heavily affect the water productivity at the farm level.

The second most important crop, banana, consumed as much as three times more water than rice. The water productivity was 0.17 and 0.32 kg m^{-3}, respectively for canal and well irrigated banana at water applications of 27,000 to 29,000 m^3 ha^{-1}.The average bunch weight of canal irrigated banana cultivar *Rasthali* was 7 kg fresh weight while it was 20 kg for well irrigated banana cultivar *Monthan*, suggesting the cultivars to explain the differences in water productivity. The perennial flower crops (Jasmine and Rose) had very low water productivity of 0.01 kg m^{-3}. Vegetables using well water on upland reached a water productivity of 0.07 kg m^{-3}.

On Farm Type 2, there was no difference in the quantity of water used in Kharif and Pishanam rice, but a higher productivity was obtained with Pishanam rice (0.38 kg m^{-3}) than Kharif rice (0.31 kg m^{-3}) due to the differences in yield. Yields were 4.2 and 3.9 t ha^{-1} for Pishanam and Kharif rice, respectively (Table 6). The second most important crop banana had a water productivity of 0.13 kg m^{-3} consuming 30,000 m^3 ha^{-1}. The pulse crop had a water productivity of 0.16 kg m^{-3} at a total water use of 3,000 m^3 ha^{-1}. The relay pulse, i.e. pulse crop sown in the standing crop of rice just before harvest, had the lowest water productivity compared with other crops (0.05 kg m^{-3}) due to the poor grain yield of 0.1 t ha^{-1}. Relay pulse crops were cultivated primarily to enhance soil fertility through legume nitrogen fixation (Senthilkumar et al., submitted-a).

Table 6. Yield (t dry weight ha^{-1}) of crops cultivated in different farm types in the Thamirabarani river basin, Tamil Nadu.

Crops	Farm Type 1	Farm Type 2	Farm Type 3	Farm Type 4
Kharif rice	3.6	3.9	4.0	-
Kharif rice (WI)	1.0	-	-	-
Pishanam rice	3.4	4.2	3.5	4.4
Pishanam rice (WI)	1.7	-	-	-
Banana	4.5	3.8	5.4	-
Banana (WI)	9.4	-	-	-
Perennials[1]	0.1	-	-	-
Relay pulse	-	0.1	-	-
Vegetables[2]	1.1	-	-	0.6
Pulses[3]	-	0.5	-	0.3
Millets[4]	-	-	-	1.2
Oilseeds[5]	-	-	-	0.1
Mixed crops[6]	-	-	-	0.2
Fodder crops[7]	-	-	-	2.1

[1] Jasmine and Rose; [2] Okra, Egg plant, Tomato, Gherkin and Onion; [3] Green gram, Black gram and Cowpea; [4] Sorghum, Pearl millet and Finger millet; [5] Sesame; [6] Cotton + Pulses and Oilseeds + Pulses; [7] Fodder sorghum and Fodder cowpea; WI = Well irrigated upland crop. ND = No determination.

On Farm Type 3, total water used for Kharif and Pishanam rice was 8300 and 9300 m^3 ha^{-1}, respectively, which was much lower than the quantities used in Farm Types 1 and 2. Water productivity of Kharif rice was highest (0.51 kg m^{-3}) in this farm type. However, with Pishanam rice it was reduced to 0.37 kg m^{-3} due to higher water use and lower yields. Banana had a water productivity of 0.18 kg DM m^{-3}.

The farmers of Type 4 cultivated only one rice crop a year by using the monsoon rainfall in the Pishanam season. The water productivity of the rice was 0.51 kg m^{-3} at a total water use of 8,700 m^3 ha^{-1}. Several other less water demanding crops were cultivated in these farms and the water productivity varied from 0.12 to 0.49 kg m^{-3} (Table 5). A variety of vegetables, pulses, oilseeds and mixed crops had a water productivity of around 0.12 kg m^{-3}. The millets and fodder crops had higher water productivities of 0.24 and 0.49 kg m^{-3}, respectively.

Water productivities of rice in Farm Types 3 and 4 were high compared to those of Farm Types 1 and 2. In general, water productivity tended to decrease with increasing accessibility to water resources. The water use in rice and the number of accessible water sources were highest in Farm Type 2 followed by Farm Types 1 and 3 and lowest in Farm Type 4 (Tables 1 & 5). However, lower water use in Farm Types 3 and 4 did not reduce the rice yields. On the other hand the rice yields were highest in Farm Type 3 in the Kharif season and in Farm Type 4 in the Pishanam season. The reverse trend on water use and rice yield as observed between large (Types 1 and 2) and small farms (Types 3 and 4) might be due to the differences in water management practices. Larger areas of 1.6 to 7.8 ha per season under rice cultivation may have led to poor water management in farms of Types 1 and 2. On the other hand, smaller areas of 0.13 to 1.5 ha per season under rice cultivation in farms of Types 3 and 4 may have led to improved water management. Furthermore, Farm Type 3 had access to canal irrigation and no well irrigation to supplement which may have reduced the water input leading to equal or higher water productivity. Farm Type 4 had no access to canal water and used only rainfall along with stored water in rainfed tanks and wells which may have resulted in a more judicious use of water.

Comparison of water productivity at crop level across farm types can be made only for those crops which were cultivated in all farm types such as rice, banana, vegetables and pulses. Strong variation in water productivity of rice was observed across farm types. Rice on Farm Type 3 had the highest water productivity in the Kharif season followed by Farm Type 1 and 2 while in this season no rice was cultivated in Farm Type 4 due to water scarcity (Table 5). Pishanam rice was the only crop cultivated among all four Farm Types. Water productivity of Pishanam rice was highest in Farm Type 4, followed by Farm Types 2, 3 and lowest in Farm Type 1.

There was not much difference in the quantity of water used by banana across farm types, however, small differences in water productivity were observed. Variation in water use and water productivity of vegetable crops between Farm Type 1 and 4 was observed. The quantity of water used by vegetables in Farm Type 1 was 14,200 m^3 ha^{-1} while it was only 6,300 m^3 ha^{-1} in Farm Type 4 which resulted in doubling the water productivity of vegetables in Farm Type 4 (Table 5).

3.1.2. Labour use and labour productivity

On Farm Type 1, the total number of labour days (hired and family labour) used for rice ranged from 74 to 136 labour days ha^{-1} (Table 7). In both the Kharif and Pishanam season, labour productivity (LP^a and LP^b – see Table 7 for explanation) was higher in canal-irrigated lowland rice than in well-irrigated upland rice. High labour use resulting from high weed infestation accompanied by poor yields reduced the labour productivity in well-irrigated Kharif and Pishanam rice cultivation. Among the lowland rice crops, Kharif rice had a higher labour productivity of 7 \$ $\$^{-1}$ invested on labour than Pishanam rice (4.7 \$ $\$^{-1}$). The labour productivity (LP^a) of lowland banana was almost double (7.7 \$ $\$^{-1}$) that of the upland banana (4 \$ $\$^{-1}$), and vegetable crops had a labour productivity of 2.9 \$ $\$^{-1}$. When valuing family labour free of cost (LP^b) the labour productivity was increased in upland banana and vegetable crops manifold and slightly in other lowland crops (Table 7). This implied more unpaid family labourers were used in the high value crops like upland banana and vegetable crops in

Table 7. Hired and family labour use (labour days ha^{-1}) and labour productivity ($ income per $ invested on labour) for the crops cultivated in different farm types in the Thamirabarani river basin, Tamil Nadu. (LP[a]) Family labour valued as hired labour, (LP[b]) Family labour valued as free.

Crops	Farm Type 1*			Farm Type 2			Farm Type 3			Farm Type 4		
	Total labour use	Labour productivity		Total labour use	Labour productivity		Total labour use	Labour productivity		Total labour use	Labour productivity	
		LP[a]	LP[b]		LP[a]	LP[b]		LP[a]	LP[b]		LP[a]	LP[b]
Kharif rice	76	7.0	7.2	107	4.8	5.9	245	2.8	3.1	-	-	-
Kharif rice (WI)	136	1.2	1.2	-	-	-	-	-	-	-	-	-
Pishanam rice	100	4.7	4.7	129	5.2	5.6	236	1.9	2.2	107	5.2	6.7
Pishanam rice (WI)	74	3.4	3.8	-	-	-	-	-	-	-	-	-
Banana	278	7.7	9.0	500	2.1	2.3	550	2.1	2.4	-	-	-
Banana (WI)	306	4.0	12.9	-	-	-	-	-	-	-	-	-
Perennials[1]	606	3.9	3.9	-	-	-	-	-	-	-	-	-
Relay pulse	-	-	-	13	4.2	17.6	-	-	-	-	-	-
Vegetables[2]	354	2.9	10.5	-	-	-	-	-	-	324	3.2	8.8
Pulses[3]	-	-	-	54	5.0	8.3	-	-	-	81	4.1	5.7
Millets[4]	-	-	-	-	-	-	-	-	-	63	5.9	7.4
Oilseeds[5]	-	-	-	-	-	-	-	-	-	22	5.6	7.4
Mixed crops[6]	-	-	-	-	-	-	-	-	-	88	3.9	7.3
Fodder crops[7]	-	-	-	-	-	-	-	-	-	89	1.4	5.4

* Permanently hired labour not included; [1] Jasmine and Rose; [2] Okra, Egg plant, Tomato, Gherkin and Onion; [3] Green gram, Black gram and Cowpea; [4] Sorghum, Pearl millet and Finger millet; [5] Sesame; [6] Cotton + Pulses and Oilseeds + Pulses; [7] Fodder sorghum and Fodder cowpea; WI = Well irrigated upland crop.

Farm Type 1. Perennial flower crops had a labour productivity of 3.9 \$ $\$^{-1}$and consumed the most labour days (606 labour d ha^{-1}) among the crops cultivated in Farm Type 1. The high labour demand for banana and perennial flower crops was due to year round existence of the crop in the field, and for vegetables due to labour intensive nature of the harvest of this crop.

On Farm Type 2, labour productivity (LP^a) in Kharif rice was 4.8 \$ $\$^{-1}$ and it was 5.2 \$ $\$^{-1}$ for Pishanam rice. Compared with Farm Type 1, labour productivity in banana was lower in Farm Type 2 due to low yield and high labour use (Tables 6 and 7). The relay and single pulse crops had a labour productivity of 4.2 and 5 \$ $\$^{-1}$, respectively.

On Farm Type 3, the Kharif and Pishanam rice had a labour productivity (LP^a) of 2.8 and 1.9 \$ $\$^{-1}$, respectively. This was the lowest labour productivity for lowland rice among all four farm types and this was due to the higher labour use on small operational scale. Banana had a labour productivity of 2.1 \$ $\$^{-1}$, similar to Farm Type 2.

The labour productivity for Pishanam rice in Farm Type 4 was 5.2 \$ $\$^{-1}$. Labour productivity ($LP^a$) ranged from 1.4 to 5.9 \$ $\$^{-1}$ in all other crops. While valuing family labour free of cost the labour productivity (LP^b) increased to 5.4 to 8.8 \$ $\$^{-1}$ for the same crops.

The observed variation in labour productivity in rice across farm types suggested that possibilities exist to increasing labour productivity in farm types where productivity was presently low. In Farm Types 2, 3 and 4 labour productivity was increased in all crops when the family labour was valued free of cost showing participation of family labourers in all cropping activities. Labour productivity tripled in the high value vegetable crops when family labour was not valued.

3.1.3. Profit and profitability

On the farms of Type 1, lowland rice and banana were the most profitable crops (Table 8). The profit from Kharif rice ranged from 244 to 574 \$ ha^{-1} and from Pishanam rice from 91 to 141 \$ ha^{-1}. A profit of 574 \$ ha^{-1} was obtained when rice was grown for seed purpose certified by the government. Profit from both upland and lowland banana were manifold higher than from rice, reaching more than 2600 \$ ha^{-1} under lowland and canal-irrigated conditions and 1266 \$ ha^{-1} under upland well-irrigated conditions. A maximum profitability of 3.3 \$ income per \$ input use was obtained with lowland banana. High fluctuations and uncertainties in profit were found in the well-irrigated upland rice, perennial flower crops and vegetables. Vegetables were cultivated only in uplands and a well managed crop earned a profit of 1188 \$ ha^{-1} but crop failure was also common due to water scarcity, pest infestation and illegal animal grazing.

Table 8. Profit ($ ha^{-1}) and profitability of crops ($ income per $ invested) in the four different rice-based farm types of Thamirabarani river basin, Tamil Nadu.

Crops	Farm Type 1			Farm Type 2			Farm Type 3			Farm Type 4		
	Profit		Profitability	Profit		Profitability	Profit		Profitability	Profit		Profitability
	Min	Max		Min	Max		Min	Max		Min	Max	
Kharif rice	244	574	0.9 – 2.2	194	286	0.6 – 1.0	4	307	0.0 – 0.8	-	-	-
Kharif rice (WI)*	-98	-98	-0.4	-	-	-	-	-	-	-	-	-
Pishanam rice	91	141	0.3 – 0.4	205	427	0.7 – 0.9	-155	138	-0.2 – 0.3	196	312	0.5 – 0.8
Pishanam rice (WI)	-176	76	-0.6 – 0.2	-	-	-	-	-	-	-	-	-
Banana	2499	2642	3.3	117	245	0.1 – 0.2	361	832	0.6 – 0.7	-	-	-
Banana (WI)*	1266	1266	1.5	-	-	-	-	-	-	-	-	-
Perennials[1]	-194	1217	-0.3 – 2.1	-	-	-	-	-	-	-	-	-
Relay pulse	-	-	-	13	37	0.3 – 0.7	-	-	-	-	-	-
Vegetables[2]	-431	1188	-1.0 – 1.5	-	-	-	-	-	-	-105	1079	-1.0 – 3.3
Pulses[3]	-	-	-	-138	205	-1.0 – 4.2	-	-	-	25	302	0.2 – 5.1
Millets[4]	-	-	-	-	-	-	-	-	-	-39	121	-0.1 – 3.0
Oilseeds[5]	-	-	-	-	-	-	-	-	-	-4	81	-0.1 – 2.4
Mixed crops[6]	-	-	-	-	-	-	-	-	-	-104	98	-0.4 – 2.3
Fodder crops[7]	-	-	-	-	-	-	-	-	-	-126	184	-0.7 – 1.1

[1] Jasmine and Rose; [2] Okra, Egg plant, Tomato, Gherkin and Onion; [3] Green gram, Black gram and Cowpea; [4] Sorghum, Pearl millet and Finger millet; [5] Sesame; [6] Cotton + Pulses and Oilseeds + Pulses; [7] Fodder sorghum and Fodder cowpea; WI = Well irrigated upland crop; *Only one crop in database.

Unprofitable cropping was found to be rare in Farm Type 2. Rice was the most profitable crop and the profit ranged for Kharif rice from 194 to 286 \$ ha^{-1} and for Pishanam rice from 205 to 427 \$ ha^{-1}. Banana was also found to be profitable in Farm Type 2 however, the profitability was lower compared with Farm Type 1 due to disease infestation. Very low profit of 13 to 37 \$ ha^{-1} was obtained with relay pulse due to small yield caused by low input use. Pulse crops were found to be highly profitable (5.2 \$ $\$^{-1}$) however crop failures were also common due to disease infestation (data not given), even leading to unprofitability.

The farms of Type 3 obtained both negative and positive profits in rice cultivation. This variation was possibly due to the small operational scale which resulted in increased input use of labour, nutrients and seed per unit area. A small change in the management practice of one into two initial ploughings modified the profit from positive to negative. Banana was in Farm Type 3 profitable as well, and the profit ranged from 361 to 832 \$ ha^{-1}.

Pishanam rice and pulses were definitely profit making crops in Farm Type 4. The profitability of all other crops, i.e. vegetables, millets, oilseeds, mixed crops and fodder crops ranged from negative to positive (Table 8). The profitability was 2 to 6 fold higher when there was enough water to irrigate these crops or when rainfall was adequate. Frequent crop failure and crop loss however, were common in these farms due to limited water availability resulting in unprofitability.

In general, banana was consistently profitable as no crop failures were recorded in any farm type, but profitability varied greatly between farm types. It was much more profitable in Farm Type 1 (profitability 2.5 to 4.3 \$ $\$^{-1}$) than in Farm Types 2 and 3. In Farm Type 2, disease infestation of banana was observed reducing the profit of this crop. Also rice, next to banana, was consistently profitable and with low risk of crop failure. The rice and banana crops were cultivated with the assured water supply from canals in Farm Types 1, 2 and 3, and the rice crop in Farm Type 4 using the monsoon rainfall resulted in consistent profitability. All other crops such as perennials, vegetables, pulses, millets, oil seeds, mixed and fodder crops were cultivated based on the farmer's decision on expected rainfall and water available from wells which resulted in large differences in profit or loss.

Rice and banana were the most important crops in Farm Types 1, 2 and 3, whereas rice was the single most important crop in Farm Type 4. Much of the available farm resources water, labour, capital and nutrients were used to cultivate rice and banana on large proportions of the available land. Though banana was more profitable than rice, cultivation of rice was predominant because rice is the staple food, has a short duration and is less risky and has a stable market. On the other hand, banana is a long duration, capital intensive crop with an unstable market.

Table 9. Partial nutrient balances of crops (kg ha^{-1}) cultivated in four different rice-based farm types in Thamirabarani river basin, Tamil Nadu, India. Nutrient balances are calculated only for completed crops. Failed and standing crops are not included in the calculation.

Crops	Partial nutrient balance (kg ha^{-1})											
	Farm Type 1			Farm Type 2			Farm Type 3			Farm Type 4		
	N	P	K	N	P	K	N	P	K	N	P	K
Kharif rice	-21	8	-56	47	12	-17	-3	-4	-108	-	-	-
Kharif rice (WI)	19	27	-56	-	-	-	-	-	-	-	-	-
Pishanam rice	-26	10	-54	-18	-1	-52	3	21	-62	-24	24	-105
Pishanam rice (WI)	22	26	-58	-	-	-	-	-	-	-	-	-
Banana	192	36	32	396	29	440	313	20	50	-	-	-
Banana (WI)	375	79	499	-	-	-	-	-	-	-	-	-
Perennials[1]	77	50	68	-	-	-	-	-	-	-	-	-
Green manure	-	-	-	9	2	12	-	-	-	-	-	-
Relay pulse	-	-	-	-3	0	-1	-	-	-	-	-	-
Vegetables[2]	98	46	56	-	-	-	-	-	-	208	60	61
Pulses[3]	-	-	-	-18	-2	-6	-	-	-	-10	0	-4
Millets[4]	-	-	-	-	-	-	-	-	-	-7	8	11
Oilseeds[5]	-	-	-	-	-	-	-	-	-	7	2	-1
Mixed crops[6]	-	-	-	-	-	-	-	-	-	15	2	9
Fodder crops[7]	-	-	-	-	-	-	-	-	-	26	7	-38

[1] Jasmine and Rose; [2] Okra, Egg plant, Tomato, Gherkin and Onion; [3] Green gram, Black gram and Cowpea; [4] Sorghum, Pearl millet and Finger millet; [5] Sesame; [6] Cotton + Pulses and Oilseeds + Pulses; [7] Fodder sorghum and Fodder cowpea; WI = Well irrigated upland crop.

3.1.4. Partial nutrient balances

To understand the nutrient flows in different cropping activities of a farm, partial crop level nutrient balances were estimated in all farms. In farms of Type 1, a negative N balance was observed in lowland rice both in Kharif and Pishanam seasons and a positive one in upland rice crops (Table 9). Positive P and negative K balances were observed in all rice crops irrespective of location and season. Contrary to rice, all other crops (banana, perennial flowers and vegetables) had a positive nutrient balances for all nutrients. Soils with banana had a large positive balance of N and K. The N balance was 192 and 375 kg ha^{-1} for lowland and upland banana, respectively. Heavy positive balance of K was found in upland banana up to 500 kg K ha^{-1}.

On farms of Type 2, Kharif rice had positive N and P balances but it was negative in Pishanam rice. K balance was negative both in Kharif and Pishanam rice. The positive N, P and a small negative K balance (-17 kg K ha^{-1}) in Kharif rice when compared to other farm types was due to incorporation of rice straw in the soil. Nutrient balances in banana were positive for all three nutrients, i.e. 396, 29 and 440 kg ha^{-1} for N, P and K, respectively. Negative nutrient balances were observed with relay and single pulse crops for all three nutrients, although values were very small.

On Farm Type 3, slightly negative and slightly positive N and P balances were observed in Kharif and Pishanam rice, respectively. Strong negative balances of K were found in both Kharif and Pishanam rice. Similar to Farm Types 1 and 2, banana in Farm Type 3 had a large positive balance of all nutrients (Table 9).

On Farm Type 4, negative N and K and positive P balances were found in Pishanam rice. Soils with vegetables had a large positive balance of all three nutrients like in Farm Type 1. Slightly negative or slightly positive balances were observed in pulses, millets, oilseeds and mixed crops in these farms (Table 9). Fodder crops had a positive N balance and a negative K balance.

3.2. Farm level resource use efficiencies across farm types

To understand the differences in resource use efficiencies across the four farm types, farm level resource use efficiencies were calculated and presented relative to the best performer (Figure. 1). Farm level water productivity, both in terms of yield (Y) and income ($) was highest in Farm Type 4 and lower in other farm types in the order of Farm Types 1, 3 and 2, respectively (Figure. 1). Availability of water resources and cultivation of rice and banana crops influenced the farm level water productivity heavily (Figure. 1 and Table 5). This implied that the available water resources were efficiently used in Type 4 farms compared to other farm types. The largest yield of 4.4 t ha^{-1} was obtained in Pishanam rice using the lowest quantity of water in Farm Type 4

(Table 6 & 5). On the other hand, Farm Types 1, 2 and 3 used more water and produced smaller yield and income suggesting the commonly available canal water was not efficiently used in these farm types.

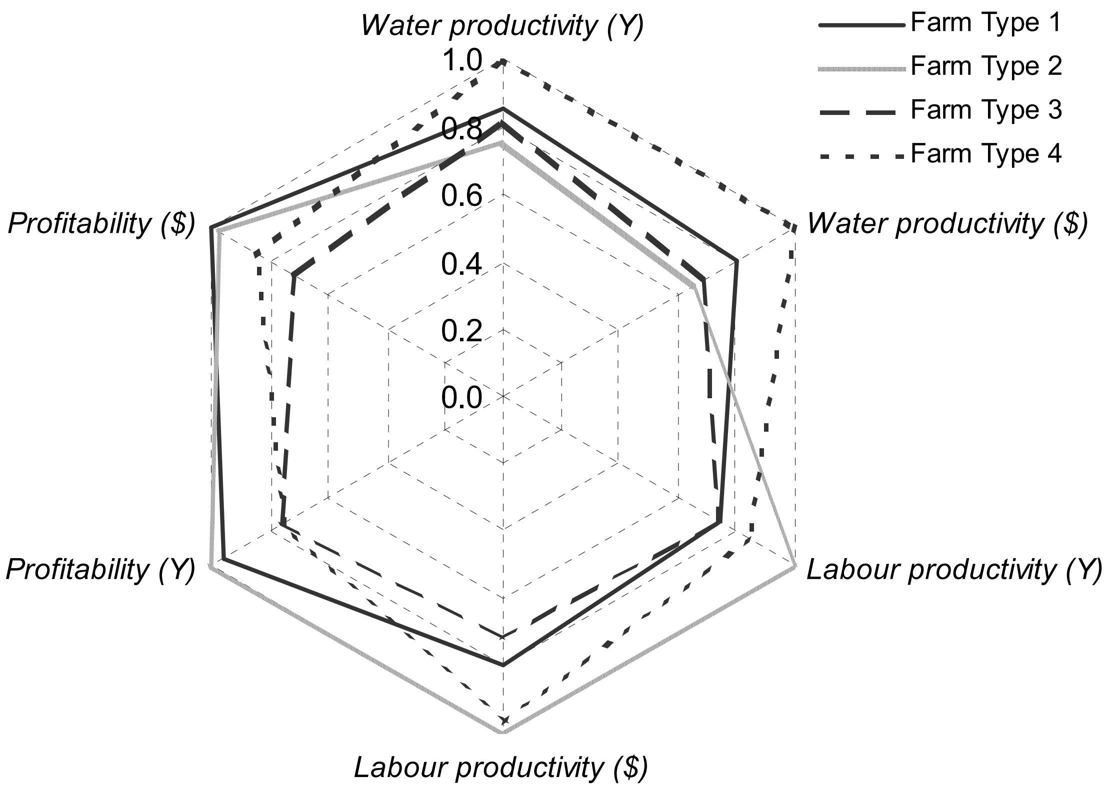

Figure 1. Resource use efficiencies of four difference rice-based farm types in Thamirabarani river basin, Tamil Nadu. Data quantified for four consecutive seasons (16 months) in 2005-06. Normalized values are calculated from 3 sample farms per farm type by using weighed averages. All crop units, both failed and standing crops are included in the calculation. The equations used are, Water productivity (Y) = kg DM yield / m^3 of water used; Water productivity ($) = $ income / m^3 of water used; Labour productivity (Y) = kg DM yield per hr of labour use (permanently + temporarily hired and family labour); Labour productivity ($) = $ income per hr of labour use (permanently + temporarily hired and family labour); Profitability (Y) = kg DM yield per $ inputs on crop; Profitability (S) = $ income per $ inputs on crop.

Labour productivity both in terms of yield and income was highest in Farm Type 2, followed by Farm Type 4, and low in Farm Types 1 and 3 (Figure. 1). Cultivation of high value crops like vegetables and pulses (Table 6) and use of more family labourers (Table 1) may be the reason for high labour productivity in Farm Types 2 and 4. The low labour productivity with Farm Type 1 may be due to the use of more hired labour and very low family labour. Women members of the farm family were not working in Farm Type 1 (Senthilkumar et al., submitted-a). Very low labour productivity in farms of Type 3 can be due to small operational scale and these farms used more hired labourers per unit area than other farm types (Senthilkumar et al., submitted-a).

Profitability both in terms of yield and income was higher in Farm Types 1 and 2 than Farm Types 3 and 4. The possible reasons for the differences in profitability between big farms (Types 1 and 2) and small farms (Types 3 and 4) were; 1) size of cultivated land area – profitability of a farm tend to decrease with lower land area and vice versa; 2) crop selection – the most profitable banana crop was cultivated in Farm Types 1 and 2 in a larger proportion of land; 3) Water availability and risk – Farm Types 1 and 2 had access to supplemental well irrigation which reduced the risk of any crop failure, and the crops can be managed better. On the other hand, Farm Type 3 did not have supplemental irrigation and Farm Type 4 depended only on rainfall though they had wells. The slightly higher profitability in terms of income in Type 4 than Type 3 may be due to the cultivation of high value crops like vegetables and pulses.

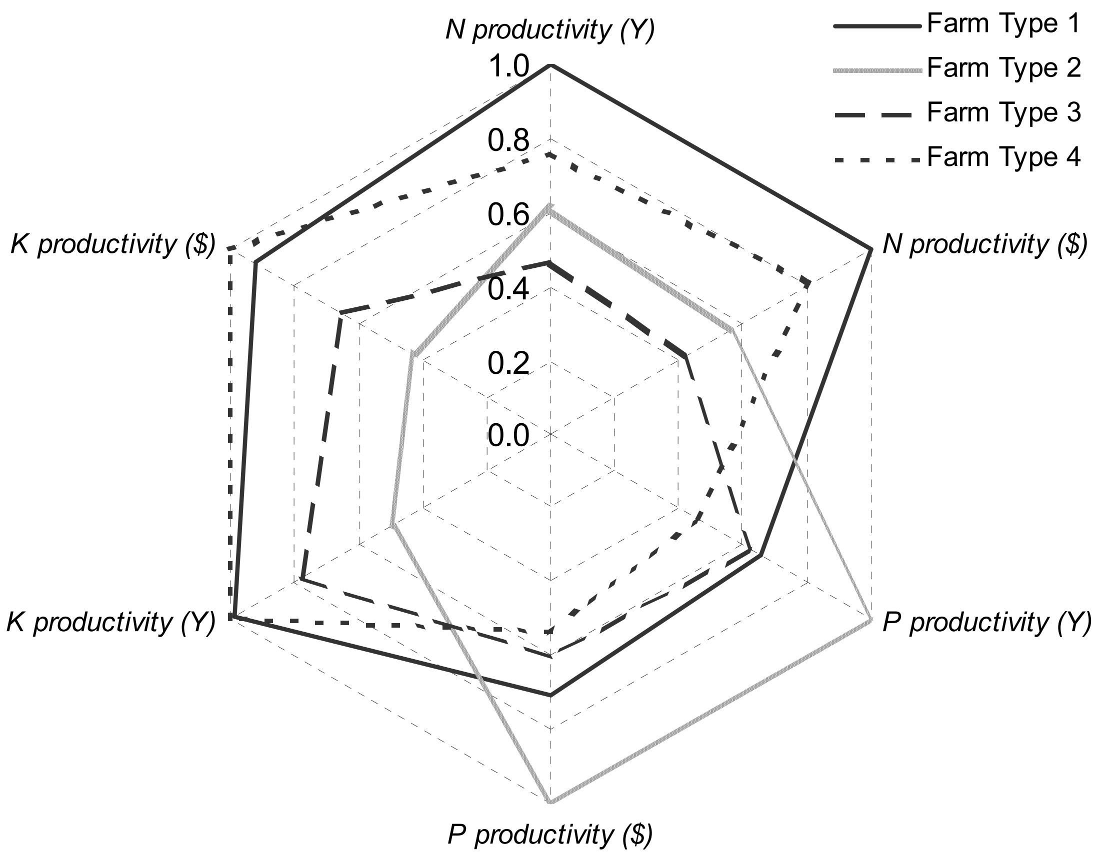

Figure 2. Nutrient use efficiencies of four difference rice-based farm types in Thamirabarani river basin, Tamil Nadu. Data quantified for four consecutive seasons (16 months) in 2005-06. Normalized values are calculated from 3 sample farms per farm type by using weighed averages. All crop units, both failed and standing crops are included in the calculation. The equations used are, NPK productivity (Y) = kg of dry matter yield / kg of NPK inflow; NPK productivity ($) = $ income / kg of NPK inflow.

Nutrient use efficiencies, expressed as N, P and K productivity both in yield and income per unit use of nutrients for the four farm types are presented in Figure. 2. Over all, nutrient productivity was highest in Farm Type 1, followed by Farm Types 4, 2 and least in Farm Type 3 (Figure. 2). This implies more fertilizer was used per unit output in Farm Type 3. Mineral fertilizer applied was highest in Farm Type 3 followed by Type 2, 1 and lowest in Type 4 (Senthilkumar et al., submitted-a). For the individual nutrients, N was efficiently used in Farm Type 1, P in Farm Type 2 and K in Farm Type 4. Individual nutrient productivity of a farm mainly depends on inflow and outflow of nutrients.

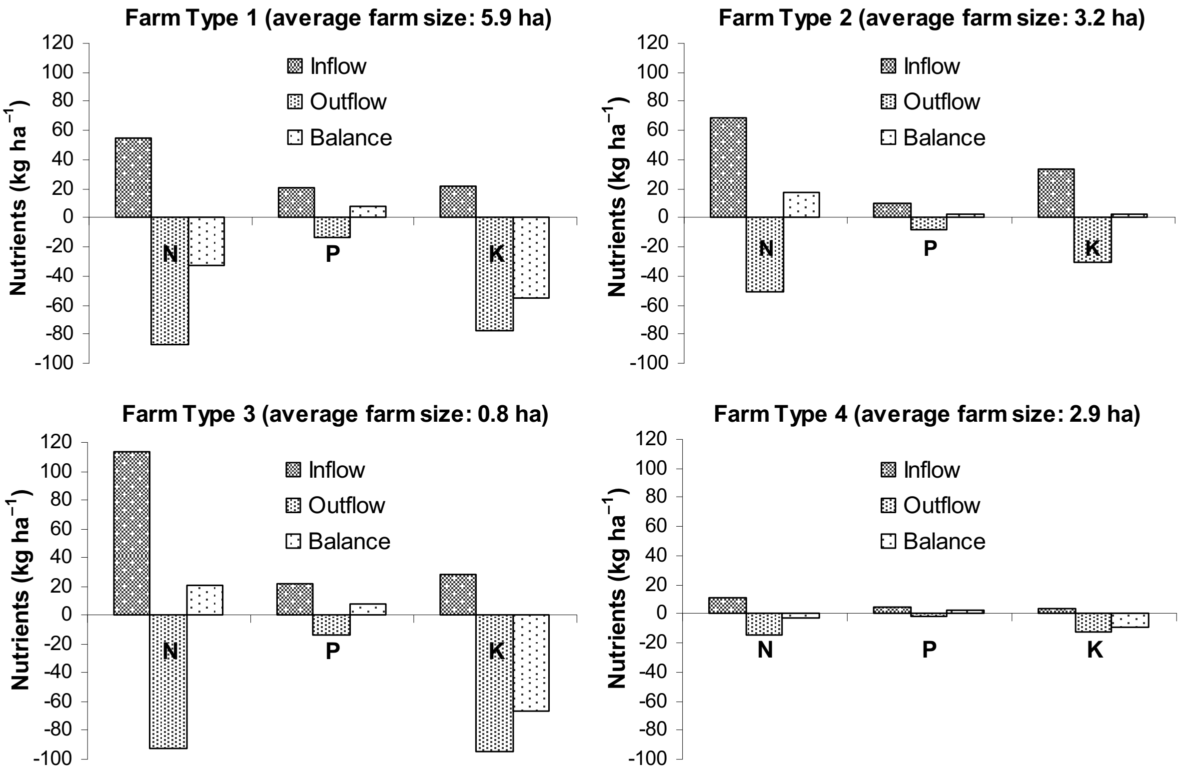

Figure 3. Farm gate partial nutrient balances (kg ha^{-1}) of four different rice-based farm types of Thamirabarani river basin, Tamil Nadu. The values are average of 3 sample farms per farm type weighted for the land area. The inflow, outflow and the balances are quantified for four consecutive seasons (16 months) from June 2005 to September 2006. Failed and standing crops are included in the calculation.

The over-all inflow and outflow of nutrients were comparatively higher in Farm Types 1, 2 and 3 than Farm Type 4 (Figure. 3). The heavy inflow and outflow of nutrients in Farm Types 1, 2 and 3 were associated with water availability and cultivation of banana. Water scarcity in Farm Type 4 resulted in very small inflow of nutrients. Nutrient and water productivity have a substantial impact on each other and also on farm-level decisions in many regions (Wichelns, 2003). Nutrient application is associated with soil moisture conditions and without sufficient moisture in the soil, farmers cannot apply fertilizers. The highest N inflow was observed in Farm Type 3 (114 kg ha^{-1}) followed by Farm Type 2 (68 kg ha^{-1}) and Farm Type 1 (55 kg ha^{-1}). A very low N inflow of 12 kg ha^{-1} was observed in farms of Type 4. P inflow was equal in Farm Type 1 and 3 (21 kg ha^{-1}) and it was 10 and 5 kg ha^{-1} in Farm Types 2 and 4, respectively. K inflow ranged from 22 to 33 kg ha^{-1} in Farm Types 1, 2 and 3 and it was only 3.4 kg ha^{-1} in Farm Type 4. The farm level partial N balance was negative in Farm Types 1 and 4 but positive in Farm Types 2 and 3 corresponding directly to the N productivity (Figures. 2 & 3). The P balance was positive in all farm types and K balance was negative in all except Farm Type 2 (Figure. 3). Strong negative K balance in Farm Types 1 and 3 was associated with the cultivation of two rice crops in a large portion of the land holding. Nearly 80 and 60% of the land was under lowland rice for two seasons in a year in Farm Types 1 and 3, respectively. Rice was harvested along with straw and taken out of the field which resulted in negative K balance in rice at field scale, and large area under rice resulted in negative K balance at farm scale. Positive balances of all three nutrients in Farm Type 2 were associated with the cultivation of banana crop in 34% of the land holding throughout the year. Only the fruit bunches were taken out of the field and the pseudo stems left over and incorporated in situ which brought back the nutrients. Crops which had a large positive nutrient balance in all four farm types were banana, perennial flower crops and vegetables (Table 9). Pulses had a negative nutrient balance; however, nitrogen fixation was not accounted for in the calculation. Assuming the grown legumes to produce 23 – 311 kg N ha^{-1} (Haynes et al., 1993; Unkovich and Pate, 2000) may explain that pulses are cultivated to enrich the soil fertility without external nutrient supply. Cultivation of millet, oilseeds, mixed and fodder crops contributed less to the overall partial nutrient balances in Farm Type 4, because of low nutrient input and low yield output due to water limitation.

The possible drawbacks in determining the resource use efficiencies were; 1) The biophysical and economic indicators quantified and expressed on a hectare basis were actually from the varying field scales. For e.g., profitability of rice in Farm Types 2 and 3 was quantified from the data collected from the actual cultivated area of 2 – 3 ha and 0.2 – 0.8 ha, respectively. The resulting values may have an extrapolation error when expressed on per ha basis. 2) Only partial nutrient balances were quantified in all farm types. The processes left out in the analysis such as atmospheric deposition, sedimentation, erosion, leaching and denitrification have an influence on the actual nutrient balances. 3) The farm level nutrient balances were quantified only for four consecutive seasons. This means that they can only indicate partial nutrient balances at a point in time. The farmers were cultivating crops which had positive nutrient balances like banana and vegetables, and also negative nutrient balances like rice and pulses in rotation. The results should be interpreted with caution, when discussing the future of the farming systems with respect to the long term soil fertility management. Nutrient dynamics over time need to be studied in detail.

Table 10. Potential impact of different policy instruments on livelihood of farmers across farm types.

Farm parameters	Farm Types	Policy instruments: Pricing on canal water	Pricing on electricity for pumping well water	Quota on canal water and electricity use	Training and education on modified rice cultivation technologies	Irrigation Infrastructure development	Organised co-operative management of common agricultural resources
Farm income	1	–	– –	–	+ +	+	+
	2	– –	– – –	–	+ +	+ +	+ +
	3	– – –	0	0	+ +	+ +	+ + +
	4	0	– – –	0	+ +	+ + +	+
Water productivity	1	+ + +	+ +	+ +	+ + +	+ + +	+ + +
	2	+ + +	+ + +	+ +	+ + +	+ + +	+ + +
	3	+ + +	0	0	+ + +	+ + +	+ + +
	4	0	+ + +	0	+ +	– / +	+
Shift in production technologies*	1	+	+ +	+	+	+ +	+ +
	2	+ +	+ + +	+ +	+ + +	+ + +	+ + +
	3	+ + +	0	0	+ +	+ +	+ +
	4	0	+	0	+ +	+ + +	+ +
Overall effect on farmers livelihoods	1	–	–	– –	+ +	+ +	+ +
	2	– –	– –	– –	+ +	+ +	+ +
	3	– – –	0	0	+ +	+ +	+ +
	4	0	– – –	0	+ +	+ + +	+ + +

The number of '+' or '–' indicates the degree of positive or negative impact relative to other farm types. The policy instruments are analysed individually for their possible impact on farm parameters. Farm Types 1&2 and 3&4 comprises 10 and 90% of the farm households and cultivating 45 and 55% of agricultural area, respectively. *Production technologies such as modified rice cultivation, less water demanding and high value crops.

3.3. Potential effect of policy instruments on enhancing resource use efficiencies and farmers' livelihoods

The four rice-based farm types differed substantially in resource use efficiencies on water, labour, capital and nutrients (Figures. 1 & 2). Factors such as crop species, land use pattern, crop management, farmer's knowledge and objectives influenced the resource use efficiencies. The potential effect of different policy instruments on enhancing resource use efficiencies and farmers livelihoods are assessed qualitatively (Table 10). Pricing on canal water will affect the farm income and in turn the farmer livelihoods heavily in Farm Type 3 and the effects will be comparatively low in Farm Types 2 and 1. On the other hand, water productivity will be enhanced in these farm types as farmers will tend to reduce the quantity of water use through a shift to water-efficient production technologies. For example, Farm Types 1 and 2 were wealthy with high annual farm income (Table 1) and they were comparatively more profitable with farming than Farm Type 3. Farms of Type 3 had a very small land holding of less than one hectare and profitability tends to reduce with small operational holding. This was the only farm type that had negative profit with lowland rice while all other farm types obtained positive profit (Table 8). Importantly, nearly 90% of the farms in the state are small farmers holding less than 2 hectare (State Planning Commission, 2004), and these farm house holds will continue to occupy a predominant position in food production to meet the growing food demand of the region (Devendra, 2007). Policies that price the water or limit its availability certainly can motivate farmers to improve water management, but public awareness programmes and moral persuasion efforts may be inefficient in areas where household land availability is a binding constraint (Wichelns, 2003). Farm Type 1was the most profitable compared with other farm types but it was not the most efficient in water and labour productivity (Figure. 1). They had the largest land holding and sufficient access to hired labour, canal water and capital resources (c.f. Table 1). Farm Type 2 had very low water productivity both in terms of yield and income but they were most efficient in labour productivity and profitability. This tends to support the statement that "farm activities tend to maximize economic output which may not necessarily coincide with the optimal use of commonly available resources from an ecological perspective" (Senthilkumar et al., 2008).

On Farm Type 4, the only water source was rainfall and stored water in wells and rainfed tanks (c.f. Table 1), but these farms had the highest water productivity both in terms of yield and income of all farm types. Limited water availability led the farmers to cultivate only one rice crop in a year and many less water demanding crops like pulses, millets and oilseeds (Senthilkumar et al., submitted-a). Farm Type 4 was second best on labour productivity but they were not as profitable as Farm Types 1 and 2. Farm Type 4 will remain unaffected for the water pricing policies as they are not using the canal water.

Government policies such as pricing electricity will influence the water productivity and farmer livelihoods in Farm Types 1, 2 and 4, whereas Farm Type 3 will remain unaffected as they did not have wells for irrigation. Farm Types 2 and 4 will be the most affected for pricing electricity since they are pumping more well water for irrigation (Table 1 and 10).

Policies such as quota on water and electricity use may be an option to protect the less profitable farms of Type 3 and 4. This may protect the farmer livelihoods of these farms but may not improve the water productivity. However, it will improve the water productivity in Farm Types 1 and 2 through the adoption of water efficient technologies. Farm Types 1 and 2 make up 10% of the farm households and they are cultivating 45% of the agricultural area in the state (Statistical Hand book, 2006). Policies such as water and electricity quotas improve the water productivity in 45% of the agricultural area though it may affect the farmer livelihoods in these farm types.

Government policies such as training and education on modified rice cultivation techniques, development of irrigation infrastructure and organised co-operative management of common agricultural resources will enhance both the resource use efficiencies and the farmer livelihoods in the region (Table 10). Training and education to farmers on modified rice cultivation techniques may improve its adoption which may lead to improved water productivity in all farm types. Earlier studies in the research area reported that farmers were positive on reduced water use with water-saving irrigation and also larger yields in rice with modified rice cultivation method. Yet adoption was hindered by the practical difficulties such as risk and uncertainty of water release and waterlogging in low-lying rice fields (Senthilkumar et al., 2008). Improving the irrigation infrastructure and creating good control over irrigation water like cementing the irrigation channels will improve the chance of adoption of water-saving irrigation in Farm Types 1, 2 and 3. Currently the cement lining of main irrigation canals are progressing in the study area (Public Works Department, 2007) and needs to be extended to subcanals for effective water control at field scale.

Practically, policy instruments like pricing and quota on water use can be introduced only after the modernization of irrigation infrastructures. Farmers then are likely to widen the number of crops cultivated with a shift towards less water demanding and more remunerative crops which will in turn improve the farmer livelihoods in all farm types. Rice cropping needs to compete with other crops in profitability which depends on the economic return per crop type and government price support policies. However, cultivating rice will not be given up as rice is the staple food and its demand is increasing with growing population. To sustain present food self sufficiency and to meet future food requirements, rice productivity needs to grow at least 3% annually (Thiyagarajan and Selvaraju, 2001). The current 15% of water resources for domestic and industrial use is expected to have increased by 25% in 2025 (Thiyagarajan et al., 2002). In this situation, increasing the rice production with less water is imperative to sustain food security.

Modernized irrigation infrastructures may result in controlled water release and distribution. However, quantifying the quantity of water use per farm to implement policy instruments on water pricing and water quotas may not be economically viable. Nearly 90% of the farmers in the state are small and marginal farmers having less than 2 ha of land holding (Statistical Hand book, 2006) and the fields of a farm are scattered. Policy instruments like institution building and organized co-operative management are useful to adopt water-saving irrigation at larger spatial scales. The existing farmers' water users association could be stimulated for this purpose.

Increased labour requirement and unwillingness of agricultural labourers for modified planting was reported as the main cause in disadoption of modified rice cultivation (Senthilkumar et al., 2008). Introducing improved technologies like planting machines will enhance the labour productivity by reducing the labour use in all farm types.

Though the study was focused on the rice-based farms, the second most important crop in Farm Types 1, 2 and 3 is banana which also contributed to the resource use efficiencies of farms. It consumed as much as three times more water and labour resources compared with rice. Large quantities of nutrients were applied to banana which resulted in large positive nutrient balances. Improved technologies to reduce the water, labour and nutrient use in banana need to be developed along with the introduction of high value crops that use less water to improve the resource use efficiencies of the rice-based farming systems.

The impact of policy measures through different instruments is different between farm types are so far identified qualitatively (Table 10), but should be quantified properly. Using Linear Programming models at farm level per farm type and dealing with multiple objectives seem to be the appropriate tools. In further research we are currently developing these models.

4. Conclusions

Differences in the resource use efficiencies of crops were observed within a farm type and across all four farm types. Rice was the most important crop and its resource use efficiency determined the farm level efficiencies, followed by banana. Variation in resource use efficiency indicators across farm types showed the possibilities for enhancing the efficiency of the scarce resources through changes in cultivation practices and policy interventions. The indicator values of the current resource use efficiencies showed the degree of adaptability of a farm type to the change in policies such as pricing water and electricity at regional level. Policy instruments such as rules and regulations (e.g. land and water quotas), public investment on education, training and infrastructure development, and institution building and organized co-operative management of the water resources are required to enhance the resource use efficiencies and farmers livelihoods. Sufficient care should be taken while bridging the objectives of both farm and regional level, i.e. improving the efficiency of the resources without harming the livelihoods of the farming community.

The possible effects of the different policy instruments on improving the resources use efficiencies and the farmers' livelihoods in each farm type need to be analysed quantitatively and comprehensive analytical tools need to be developed for this purpose.

Acknowledgement

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Chapter 5

Policies to support economic and environmental goals at farm and regional scales: Outcomes for rice farmers in Southern India depend on their resource endowments†

† Adapted with modifications from:

Senthilkumar, K., Lubbers, M.T.M.H., de Ridder, N., Bindraban, P.S., Thiyagarajan, T.M., Giller, K.E. (in prep). Policies to support economic and environmental goals at farm and regional scales: Outcomes for rice farmers in Southern India depend on their resource endowments.

Senthilkumar, K., Lubbers, M., de Ridder, N., Bindraban, P.S., Giller, K.E., 2007. Exploring alternatives for sustainable rice-based farming systems in Tamil Nadu, India. In: Farming Systems Design 2007, Int. Symposium on Methodologies on Integrated Analysis of Farm Production Systems, M. Donatelli, J. Hatfield, A. Rizzoli Eds., Catania (Italy), 10-12 September 2007, book 1-Farm-regional scale design and improvement, p. 39-40.

Abstract

Water resources should increasingly be used more efficiently, as they are becoming scarce while more food has to be produced. Farmers tend to maximize the economic output of their farming activities which may not coincide with an ecologically most efficient use of available water resources. Water-efficient cultivation practices for rice that gave no yield penalty were, for instance, not adopted by the farmers because of the open access to water resources, poor irrigation infrastructure, the lack of incentives and required changes in social-cultural attitudes to rice cultivation. However, improving water use efficiencies at farm scale can be of overall importance at the regional level and, therefore, to society at large. Well-chosen combinations of policy measures on water use and water-saving technologies such as modified rice cultivation are therefore needed to enhance the efficient use of water within a given region without jeopardizing the livelihood of poor farmers. In this study, we developed a multi objective linear programming (MGLP) model to explore the impact: i) of modified rice cultivation, which includes water-saving irrigation as one of the components, on farm profit; ii) of government policies on water pricing and water quota on adoption of water-saving irrigation in rice; and iii) of a combination of (i) and (ii) to achieve the objectives of both farmers and society at large. The analysis was carried out on four rice-based farm types for the state of Tamil Nadu, South India. Model results showed that observed farm profit of all four farm types could be increased using current practices simply by optimizing land use for specific crops. Adoption of modified rice cultivation further increased farm profit. Water-saving practices were chosen only when water pricing policies were introduced. Farm profits were reduced even at low levels of water pricing but that can be compensated by farmers by adopting modified rice cultivation. The combination of modified rice cultivation and government policies on water pricing was effective in achieving both increased farmer income and saving water, though the required level of water pricing differed across the farm types and season and affected poor resource-endowed farmers the most. Providing water quotas can be an option to protect the poor resource-endowed farmers. The model was useful to identify the optimal level of water pricing and water quota for each farm type to achieve the objectives of both farmers and society at large.

Keywords: Modified rice cultivation; linear programming; optimization; water pricing policy; water-saving irrigation; farmer livelihoods

1. Introduction

Farmer's livelihoods in Tamil Nadu, South India depend on scarce resources of land, water, labour and capital. Rice (*Oryza sativa* L.) is the predominant crop that consumes 70% of water available for irrigation. Inefficient use of water in rice cultivation leads to a scarcity and competition for irrigation water with other crops. Modifications in rice cultivation have been found to reduce water use in rice while maintaining or increasing yields. Experiments were conducted to compare modified rice cultivation including water-saving irrigation techniques with conventional practices under on-station and on-farm conditions (Senthilkumar et al., 2008). A combination of modified planting, mechanical weeding and green manure application with or without water-saving irrigation increased the grain yield significantly (Senthilkumar et al., 2008). With water-saving irrigation, up to 40% less water was used without yield reduction, leading to an increase in water productivity by 90% (Thiyagarajan et al., 2002; Senthilkumar et al., 2008). Farmers did not adopt modified rice cultivation methods due to technical difficulties in the novel cultivation practices, labour constraints and gender issues (Senthilkumar et al., 2008).

Table 1. Farm resource endowments and characteristics of the identified four farm types. Data are per farm per year, averaged over three sample farms based on Senthilkumar et al., (submitted-a)

Farm resource endowments and characteristics	Farm Type 1	Farm Type 2	Farm Type 3	Farm Type 4
Land available (ha)	6	3	1	3
Family labour use (Labour days)	98	357	144	73
Hired labour use (Labour days)	1,244	759	247	275
Water use (10^3 x m^3)				
Canal	66.1	8.8	7.9	0.0
System tank	0.0	7.3	0.0	0.0
Well	9.0	34.9	0.0	4.2
Rainfed tank	0.0	0.0	0.0	0.1
Rainfall	50.5	25.0	7.8	27.4
Farm net income (US$)				
Crops	2,349	1,498	146	305
Animals	46	181	34	78
Off-farm	4759	2496	922	824

A comprehensive analysis of the farm characteristics was made to understand the factors that determine adoption (Senthilkumar et al., submitted-a). Four rice-based farm types were identified that differed substantially in farm resource endowments and characteristics in the research area (Table 1), leading to variation in income and livelihood strategy of the farm family. Qualitative assessment revealed opportunities for adoption of one or more components of the modified rice cultivation practices, depending on farm type, and the need for conducive government policy measures for more widespread and effective adoption (Senthilkumar et al., submitted-a). The current use efficiencies of resources in each farm type were quantified and the potential effect of different policy measures on enhancing these efficiencies, along with the implications on farmers livelihoods, were qualitatively assessed (Senthilkumar et al., submitted-b). As the impact of policy measures on farm income and livelihoods depend greatly on farmer's objectives, farm structure and functioning and resource endowment, a quantitative assessment of these effects remained necessary for the evaluation of policy measures.

Table 2. Research questions aimed to be answered by model analysis.

Research questions	Model analysis	Results presented in
What is the optimal land use pattern with the current farm practices to achieve maximum farm profit?	Step 1: Optimizing for maximum profit with the current farm practices.	Table 4 (model run B) and Figure. 1 (model run B)
How the farm profit will be affected by adopting one or more components of the modified rice cultivation to the conventional rice cultivation?	Step 2: Impose one or more components of the modified rice cultivation to the conventional rice cultivation.	Table 5
What is the impact of different level of water pricing on farm profit?	Step 3: Impose different price levels for the available water resources excluding rainfall.	Table 6, Figure. 2 (conventional rice cultivation), Figure. 3 and Figure. 4
Will adoption of modified rice cultivation support farmers to sustain farm profit with water pricing? If so, up to which level of water pricing?	Step 4: Including both modified rice cultivation and different water pricing levels.	Figure. 2 (modified rice cultivation) and Table 7
If water is priced, can all the four farm types sustain their farm profit by adopting modified rice cultivation? If not, what will be the quantity of water quota need to be given to each farm type in order to sustain their farm profit as well as to adopt modified rice cultivation?	Step 5: Introducing different level of water pricing and water quota with modified rice cultivation.	Figure. 5

Optimization models based on Multiple Goal Linear Programming (MGLP) are generally used in farm explorative studies (Mendoza et al., 1986; de Wit et al., 1988; Hengsdijk and van Ittersum, 2002). Its application supports identification of feasible land use patterns and trade-offs between different biophysical and socio-economic objectives (Rossing et al., 1997; van Ittersum and Rabbinge, 1997; van Ittersum et al., 1998). To quantify trade-offs, objectives are individually optimized, with restrictions on the other objectives. Therefore, the method can support feasible end-points of development, land use patterns, within a wide range of technical and socio-economic scenarios and a variety of aims and aspirations of various stakeholders at farm and regional level, the objectives. At farm level, optimal combinations of cropping activities to achieve maximum profit can be identified, while it enables policy planning at regional level to formulate efficiently regional development policies both in enhancing farmers livelihoods and resource conservation (de Wit et al., 1988). The aim of the approach is not to predict, but to explore the windows of opportunities (van Ittersum et al., 1998; Kropff et al., 2001). Though the model designed for this study contains more objective functions we only optimised one objective function, i.e. maximizing farm profit. A trade-off analysis using the other objectives was not part of this study.

The main objectives of this study were to: 1) to analyse the impact of modified rice cultivation and government water pricing policies on farmers livelihoods in the four different farm types; and 2) to assess, *ex-ante*, the impact of water pricing and water quota[‡] levels on farm profit in each farm type and at which levels shifts occur from conventional irrigation in rice towards water-saving irrigation. The above two objectives were later transformed into five research questions (Table 2) and were analysed in five steps using linear programming.

2. Materials and methods

2.1. The modeling approach

A static farm-level multi-objective linear programming model (MGLP) (de Wit et al., 1988) was developed using the General Algebraic Modeling System (GAMS) and can be solved by using either CONOPT or CPLEX solver (McCarl and Spreen, 1997; McCarl, 2007). The analysis focused on the four farm types of the rice-based farming system, however, other crops cultivated by the farmers such as banana, pulses, vegetables etc. were also included. The analysis was performed for a period of one year which comprised three cropping seasons. Livestock is not included in the model as they contributed less than 5% of the annual farm income in all four farm types (Senthilkumar et al., submitted-a).

The mathematical formulation of an MGLP model is similar to that of any LP model (see Appendix for complete mathematical formulation of the model):

Maximize or Minimize $\{w_n = \underline{c}_n{}'\underline{x}\}$

[‡] A quantity of water available to a farmer free of cost and the excess water used is priced as normal.

Subject to:
$A\underline{x} = \underline{b}$
$\underline{x} \geq \underline{0}$

where w_n are the objective functions: linear functions of the production activities (x, the decision variables) and their respective contributions (c: vector of coefficients) to the objectives. A is an $m \times n$ matrix with input–output coefficients for all production activities and $\underline{b}$ represents the $m \times 1$ right hand side (RHS) vector, i.e. the thresholds values for the restrictions. Each land use activity is completely characterized by its relevant input and output coefficients and is identified by the combinations of a number of definition criteria (in this case: crop type (cc), area type (ac), period of cultivation–weeks (w) and management practices (mp)). The latter points at conventional cultivation of all crops including rice and modified practices in cultivating rice crops where the modifications are type of planting (square planting of less than 15 day-old seedlings in wider spacing), irrigation (keeping a thin layer of water 2 cm up to flowering), weeding (mechanical weeding using rotary or cono weeder) and nutrient management (fertilizer with additional organic manure). A single modification or any combination of the four is considered as one activity in modified rice cultivation, i.e. leading to 15 modified rice cultivation techniques. In addition to other crops that can be cultivated, 16 rice cultivation methods (1 conventional and 15 modified) to produce rice are thus created for the model to select.

The model was designed to explore possibilities for different combinations of land use activities under different scenarios, i.e. a trade-off analysis between objective functions. In this study, we only optimised income and left the other objectives free. Main outcomes of the model are the selected land use activities, the area of each activity in a time period of one year and the values for the objective function i.e. income.

The objective function of the model is maximization of farm profit (MAXPROFIT; US\$ y^{-1}). Maximizing farm profit is usually the main objective of the farmers. The optimal values of the objective function is subject to the resource endowments of the farm such as available land, labour and water. Each farm type has: 1) a maximum land area per land type that can be used for cultivating crops; 2) a maximum quantity of water available per week per water source; 3) a maximum number of family and hired labour (both men and women) available to a farm per week; and 4) a minimum amount of rice to be produced both in Kharif and Pishanam seasons to meet family food requirements.

Specific constraints to each farm type (Table 3) are formulated to avoid extreme outcomes. They are: 1) that a particular vegetable crop could not be cultivated on more than 0.2 ha in a farm, reflecting market restrictions, such as drastic price fall or unsold products on a satisfied market if all farmers in the region produce more vegetables than required for local consumption; 2) that the maximum area for banana is limited and varies and depends on the resource endowments of a farm type. The limitations to banana cultivation are: a) required high capital investment; b) associated risk on price for banana, wind/cyclone damage and disease infestation; c) long crop cycle, i.e. farmers have to wait a year to harvest. However, model analysis also was carried out to quantify the maximum profit a farmer could obtain by removing the boundaries to these specific constraints.

Table 3. List of constraints included in the model analysis per farm type.

Constraints		Farm Type 1	Farm Type 2	Farm Type 3	Farm Type 4
Maximum available land (ha)	Wetland	5.0	3.0	1.0	0.0
	Irrigated dry land	1.0	0.0	0.0	3.0
Maximum crop area* (ha)	Banana	≤ 0.6	≤ 1.0	≤ 0.5	-
	Banana (WI)	≤ 0.4	-	-	-
	Per vegetable crop (WI)	≤ 0.2	≤ 0.2	-	≤ 0.2
Fraction of rice nursery to plant main rice crop (ha ha^{-1})	Rice (ha)	0.08	0.08	0.08	0.08
Minimum quantity of rice required for family consumption (kg y^{-1})[a]		700	900	500	400
Machine maintenance cost (US$ y^{-1})[b]		200	100	0	50
Cost of hiring permanent labour (US$ y^{-1})[b]		300	0	0	0

WI = Well irrigated crop; [a] Calculated from the per capita consumption of rice in developing countries, i.e. 68.5 kg y^{-1} milled rice or 100 kg paddy y^{-1} (FAO statistics); [b] Average values for the farm types observed during the farm survey; costs are common to all crops and recurring every year. * constraint removed for the model runs D and E presented in Table 4 and Figure. 1.

2.2. Data collection and model parameterization

An in-depth farm survey was conducted on representative farms for the identified four rice-based farm types during four consecutive cropping seasons (16 months) from June 2005 to September 2006. Farms were located in the Thamirabarani river basin. A detailed description of the four farm types was presented by Senthilkumar et al., (submitted-a). Input data on water, labour, seed, fertilizers, pesticides and machineries and output data on main product yield (e.g. grain, fruit and tuber) and by-product yield (e.g. straw and stover) and nitrogen balances for each cropping activity were quantified through weekly farm surveys in farms representative of each farm type. Water use from canals, system tanks[§] and rainfed tanks (fed only by rainfall) was measured using a Parshall flume and from wells by calibrating the electric/diesel motor discharge rate and recording the duration of pumping. Rainfall was measured using rain gauges installed on each farm. Days of family and hired labour use, taking 8 hrs per labour-day as a standard, was quantified for each operation in all cropping

[§] Tanks that are fed by canals from the river and that provide irrigation water for a longer period than canals.

activities. The weekly field data were used to create the input and output tables for each farm type.

Initially, to verify the performance of the model, the exact quantity of inputs used per week in a sample farm per farm type was parameterized and optimized for maximum profit. The model produced similar land use and farm profit to what was observed in the respective farms in all farm types. This was done to show that technically the model performs as expected. Later, to allow the model to select land use choices freely, the maximum quantity of water and labour a farmer can access with his resource endowments were used as the maximum quantity available for all cropping activities in a week. The crops that can be grown in a particular period (weeks) were prescribed to portray the real situation. In order to eliminate the effect of specific farmer preferences and farmers' skills on crop performance, virtual farms per farm type were defined. This was done by eliminating sole cropping activities specific to single farms (e.g. rose, rice cultivated for seed production), and by using the input and output data of average crops as cultivated in all farms in a particular cropping period (e.g. Kharif and Pishanam rice). The average data per virtual farm describe the current situation and management is defined as 'conventional' in further analysis. The yield, water and labour coefficients of the modified rice cultivation activities are obtained by multiplying the coefficients of the conventional rice production activity with appropriate multiplication factors which are based on the field experiments (Senthilkumar et al., 2008). The modifications with modified rice cultivation over conventional rice cultivation comprised the following practices. First, instead of 24 – 35 days old seedlings from lowland nursery beds (P_1), 14 – 15 days old seedlings from a modified nursery[**] were planted with wider spacing in a square pattern (P_2). Second, the conventional practice of irrigation to 5 cm water depth one day after disappearance (I_1) was replaced up to flowering by a thin water layer of 2 cm by irrigating when small cracks appeared on the soil surface, generally within 2 – 3 days after disappearance of the water layer (I_2). After flowering, fields were irrigated immediately after disappearance of the standing water. Third, manual hand weeding twice at around 20 and 40 days after transplanting (W_1) was replaced by mechanical weeding every 10 days up to 40 – 45 days after planting, starting at 10 days after transplanting (W_2). Fourth, recommended mineral fertilizer (N_1) was supplemented with 6.25 t ha^{-1} green manure (N_2).

2.3. Model runs

The model was run with different combinations of decision variables offered and coefficient values for water pricing in the following steps: Step 1) only current farm practices (base run); Step 2) adding options for modified rice cultivation; Step 3)

[**] Dapog: a nursery method developed in the Philippines, were seedlings are raised on a surface, like a polythene sheet, so they can be easily transported to the field and transplanted at a young age.

pricing water with only current farm practices; Step 4) as under three but adding options for modified rice cultivation; Step 5) as 4 but adding quota of water free of costs to mitigate effect of water prices. Changes in the model results for the runs 2 to 5 were expressed relative to the first run. The research questions we chose to answer in this model study are described in Table 2. The experimental structure of the model analysis was 2 × 2 × 4, which included two types of rice cultivation (conventional and modified), two government policy instruments (water pricing and water quota) and the four different farm types. Water use from different water resources such as canal, system tank, well, rainfed tank but excluding rainfall were priced at the same rate across the four farm types to keep the analysis simple.

3. Results

Step 1: Profit maximization for current farm practices – base run

The optimized farm profit with current farm practices was 2512, 1323, 472 and 1494 US\$ y^{-1} in Farm Types 1 to 4, respectively (Figure. 1). In Farm Type 1, the optimized profit was 7% higher than the observed profit and land use selected by the model is slightly different from what farmers do currently; the model did not select well-irrigated Pishanam rice and tomato (Table 4). The model selected banana as the most profitable crop in the lowlands up to the maximum allowed land for banana (see Table 3 for crop area constraints). On the remaining land the model selected Kharif and Phisanam rice (Table 4). When the land constraints on crop area were removed, more than 50% of the available lowland was selected to cultivate banana; more was not possible because water availability in the summer season limits further expansion. The remaining 50% of the lowland was selected for rice. In well-irrigated drylands, 80% of the land was selected to cultivate vegetables and the remaining 20% was used for well-irrigated banana. When crop area constraints were removed, neither well-irrigated banana nor vegetables were selected except the tuber crop. The well water then becoming available was used to irrigate the lowland banana in the summer season since canal water in this period is limited.

In Farm Type 2, the optimized farm profit was 12% lower than observed profit. However, in the model analysis we eliminated the option to cultivate rice crops for seed production. The rice seed fetches double the price of rice grain. The model selected nearly 93% of available land for cultivation of rice and the remaining 7% for green gram, while banana, black gram, and relay pulses were not selected (Table 4). Though banana was currently cultivated by farmers of this type, the model did not select this option because it was less profitable than rice and green gram. Banana in this farm type was infested by diseases in the year of observation giving a low profit (Senthilkumar et al., submitted-b). The land use selection by the model remained unchanged after removing crop area constraints (see Table 3).

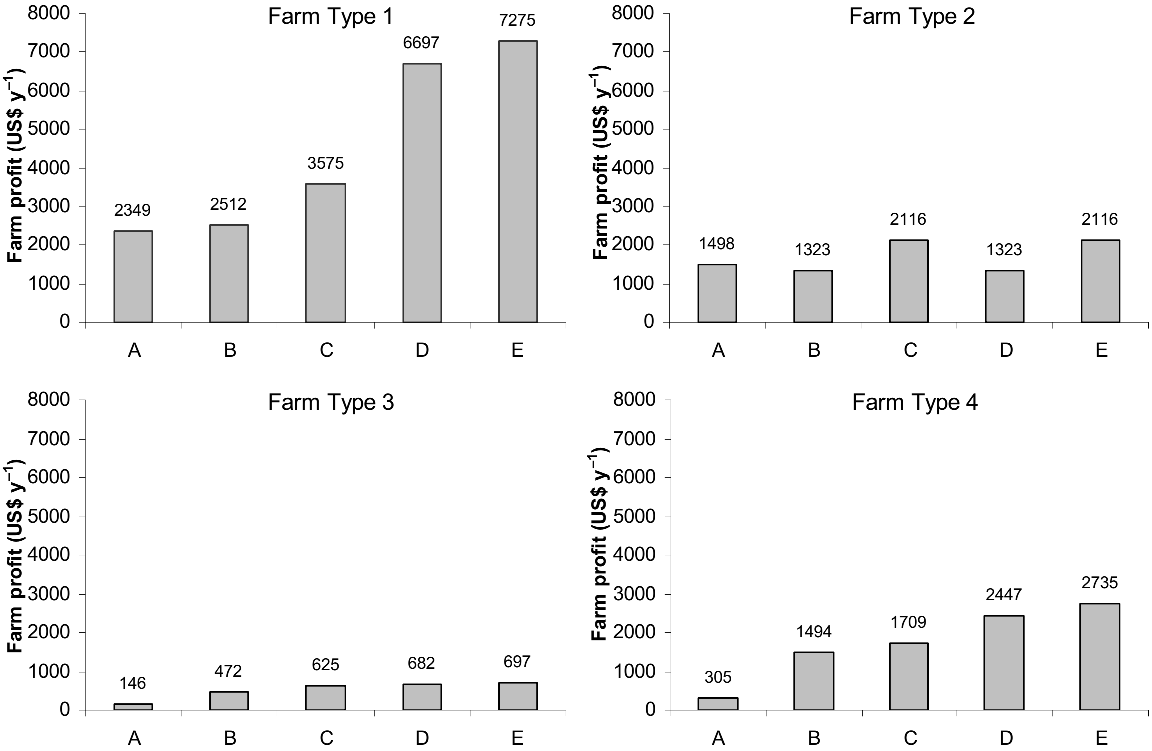

Figure.1. Observed (A) and optimized (B-E) farm profit (US$ y^{-1}) in the four different rice-based farm types. B) with constraints on crop area + conventional rice cultivation; C) with constraints on crop area + modified rice cultivation; D) no constraints on crop area + conventional rice cultivation; E) no constraints on crop area + modified rice cultivation. For constraints on crop area see Table 3 and for land use activities see Table 4.

In Farm Type 3, more than 200% increase in farm profit was obtained with model optimization in land use compared to observed profit. This difference was due to the model selection of a higher proportion of land under banana (Table 4). The profitable banana was selected at 50% of the land up to the maximum allowed by the crop area constraint (Table 3); the remaining 50% was allocated to cultivate rice. When the crop area constraints were removed, 95% of the land was allocated to banana and the remaining 5% to rice in both seasons to satisfy the family rice needs.

In Farm Type 4, farm profit was nearly 400% higher for the optimized land use (US$ 1494 y^{-1}) compared with the observed profit. Less water demanding crops such as pulses (e.g. green gram and black gram) and oilseeds (e.g. sesame) were selected by the model allocating much of the land area to these crops followed by the highly profitable vegetables (e.g. tomato, gherkin and onion) up to the maximum allowed 0.2 ha of the land. Rice was selected only on 0.2 ha of the land area. With no constraint on crop area the farm profit calculated by the model further increased to US$ 2447 y^{-1} by allocating more area to cultivation of tomato, onion, and Pishanam rice (Table 4). Many crops which were currently being grown in this farm type such as cowpea, sorghum, millets and intercrops were not selected by the model as they are less profitable than rice, vegetables, green gram and black gram.

Table 4. Current land use (A), model optimized land uses (B-E) for conventional and modified rice cultivation with or without crop area constraints in the four rice-based farm types.

Farm Types	Crop activities	Land area (ha) allocated per cropping activity				
		Model runs				
		A[§]	B	C	D	E
1	Kharif rice	1.06 – 6.00	4.40	[a]4.40	2.28	[a,b]2.28
	Pishanam rice	1.60 – 6.00	4.40	[a]4.40	2.14	[a]2.28
	Pishanam rice (WI)	0.80	0	[a]0.19	0	[a]0.62
	Banana	0.50 – 0.75	0.60	0.60	2.72	2.72
	Banana (WI)	0.16 – 0.20	0.20	0.21	0	0
	Ladiesfinger_1	0.06 – 0.10	0.20	0.20	0	0
	Ladiesfinger_2	0.06 – 0.10	0.20	0.20	0	0
	Tuber	0.16	0.20	0.20	0.18	0
	Brinjal_Clusterbean*	0.07 – 0.10	0.20	0	0	0
	Tomato	0.08 – 0.10	0	0	0	0
2	Kharif rice	1.50 – 3.00	2.78	[a]2.78	2.78	[a]2.78
	Pishanam rice	2.00 – 3.00	2.78	[a]2.78	2.78	[a]2.78
	Green gram	0.10 – 0.20	0.22	0.22	0.22	0.22
	Black gram	0.35	0	0	0	0
	Banana	0.42 – 0.70	0	0	0	0
	Relay pulse_1	1.30 – 3.00	0	0	0	0
	Relay pulse_2	1.30 – 3.00	0	0	0	0
3	Kharif rice	0.13 – 1.00	0.50	[a]0.50	0.05	[a]0.05
	Pishanam rice	0.10 – 0.78	0.46	[a]0.46	0.04	[a]0.04
	Banana	0.18 – 0.42	0.50	0.50	0.95	0.95
4	Phisanam rice	0.75 – 1.50	0.19	[a]2.78	0.99	[a]2.78
	Tomato	0.06	0.20	0.20	1.07	1.07
	Gherkin	0.29 – 0.32	0.20	0.20	0.04	0.06
	Onion	0.26	0.20	0.20	0.42	0.42
	Green gram	0.10 – 0.16	2.80	0	1.93	0
	Black gram	0.19 – 0.86	1.97	1.97	2.08	2.06
	Sesame	0.58	0.83	0.83	0.89	0.88
	Cowpea	0.13 – 0.16	0	0	0	0
	Sorghum	0.06 – 0.22	0	0	0	0
	Finger millet	0.10	0	0	0	0
	Pearl millet	0.21 – 0.67	0	0	0	0
	Blackgram_Sesame*	0.16 – 1.34	0	0	0	0
	Sorghum_Sesame*	0.42	0	0	0	0
	Cotton_Black gram*	0.35 – 0.42	0	0	0	0

Scenarios: A) observed; B) with constraints on crop area + conventional rice cultivation; C) with constraints on crop area + modified rice cultivation; D) no constraints on crop area + conventional rice cultivation; E) no constraints on crop area + modified rice cultivation. For constraints on crop area per farm type see Table 3 and for farm profit see Figure. 1. WI = Well irrigated; *Intercrop; For constraints of crop area in each farm type see Table 3; [a]$P_2I_1W_2N_2$ combination; [a]$P_2I_1W_2N_2$ and [b]$P_2I_2W_2N_2$ combination at 43 and 57% rice area, respectively. All rice crops had 0.08 ha ha^{-1} of rice nursery area. Crops with numbers are cultivated different periods of the year. [§]Crop area with single value are only one crop in database. 0 = crop activity not selected.

Overall, farm profit for the observed and optimized land use did not differ much in Farm Types 1 and 2 but large differences are observed in Farm Types 3 and 4, revealing the opportunities available to increase farm profit even without the introduction of modified rice cultivation in the latter farm types.

The differences between the observed and optimized land use could be attributed to the limitations of the model. The limitations were its static nature and parameterization based on data collected for a field duration of 4 seasons that last for 16 months. This may limit the number of crop choices per farm type in this analysis. For instance, farmers may have more crop choices over a long time period and the unprofitable crops, e.g. banana in Farm Type 2, may become more profitable as in Farm Types 1 and 3 in the next season. Including more crop choices per farm type may influence the results of the analysis. The model results are produced for the conditions that prevailed internal and external to the farm during the farm survey. The model did not deal with variability in the market conditions, weather, pest or disease outbreak and farmers preferences.

Step2: Introduction of modified rice cultivation in the model

The farm profit as calculated by the model if modified rice cultivation was included as a land use option, was 42%, 60%, 32% and 14% higher in Farm Types 1 to 4, respectively, compared with the base run where only conventional rice cultivation could be selected (Table 5). Adding modified rice cultivation options did not alter the rice area both in Kharif and Pishanam season in Farm Types 1, 2 and 3 but now modified rice cultivation options as modified planting (P_2), mechanical weeding (W_2) and organic manure application (N_2) were selected instead of conventional practices (Table 4). The combination with conventional irrigation ($P_2I_1W_2N_2$) had highest yield and is thus preferably selected. The combination with water-saving irrigation was not selected since the irrigation water was available free of cost. In Farm Type 1, releasing constraints on crop area (model run E in Figure.1 and Table 4) led to selection of more area under well-irrigated Pishanam rice and of rice cultivation with water-saving irrigation in combination with all other modified practices in 57% of the Kharif rice area. In Farm Type 4, the Pishanam rice area 2.8 ha in comparison to 0.2 ha in the base run and modified rice cultivation was selected ($P_2I_1W_2N_2$). The rice area remained unchanged when the crop area constraints were removed.

Including the modified rice cultivation options in the model had a higher impact on farm profit in Farm Types 1, 2 and 3 than in Farm Type 4 which directly was related to the proportion of land area used for rice cultivation. In all four farm types, the land use options with mechanical weeding or organic manure alone did not have any effect on the overall farm profit. Water-saving irrigation alone increased the farm profit by 0.1 to 2% while modified planting alone changed the farm profit by 2 to 20% (Table 5)

Table 5. Optimized farm profit when introducing one or more combinations of modified rice components in the four rice-based farm types.

Components of modified rice cultivation	Farm Type 1		Farm Type 2		Farm Type 3		Farm Type 4	
	Farm profit (US$ y^{-1})	% income gain over base run	Farm profit (US$ y^{-1})	% income gain over base run	Farm profit (US$ y^{-1})	% income gain over base run	Farm profit (US$ y^{-1})	% income gain over base run
$P_1I_1W_1N_1$ (base run)	2512	0.0	1323	0.0	472	0.0	1494	0.0
P_2	3007	19.7	1740	31.5	545	15.3	1516	1.5
I_2	2547	1.4	1348	1.9	477	1.1	1495	0.1
W_2	2512	0.0	1323	0.0	472	0.0	1494	0.0
N_2	2512	0.0	1323	0.0	472	0.0	1494	0.0
P_2I_2	3007	19.7	1740	31.5	545	15.3	1516	1.5
P_2W_2	3007	19.7	1740	31.5	545	15.3	1516	1.5
P_2N_2	3007	19.7	1740	31.5	545	15.3	1516	1.5
I_2W_2	3060	21.8	1721	30.1	552	16.7	1509	1.0
I_2N_2	2547	1.4	1358	2.7	477	1.1	1496	0.1
W_2N_2	2651	5.5	1437	8.6	493	4.2	1499	0.3
$P_2I_2W_2$	3060	21.8	1740	31.5	552	16.7	1516	1.5
$P_2I_2N_2$	3007	19.7	1740	31.5	545	15.3	1516	1.5
$P_2W_2N_2$	3575	42.3	2116	59.9	625	32.3	1709	14.4
$I_2W_2N_2$	3060	21.8	1721	30.1	552	16.7	1509	1.0
$P_2I_2W_2N_2$	3575	42.3	2116	59.9	625	32.3	1709	14.4

P_1 = Conventional planting; I_1 = Conventional flood irrigation; W_1 = Conventional hand weeding; N_1 = Only chemical fertilizer; P_2 = Modified planting; I_2 = Water-saving irrigation; W_2 = Mechanical weeding; N_2 = Green manure application along with recommended chemical fertilizers.

across the farm types, because of the associated yield increase. In all four farm types, including water-saving irrigation as an option or not, along with modified planting, mechanical weeding and organic manure application resulted in no difference in farm profit, which showed that the option of water-saving irrigation did not give additional profit. Hence, water pricing as a means to oblige farmers to adopt water-saving irrigation in rice became important for the analysis.

Step3: Pricing water under current farm practices

Introducing pricing to water use in the model decreased the farm profit drastically in all four farm types. At US$ 0.01 m^{-3} of water, the optimized farm profit decreased by 22%, 7%, 31% and 4% in Farm Types 1 to 4, respectively, compared with the optimized farm profit without water pricing (Figure. 2). The profit reaches zero or became negative at a water price of US$ 0.1 m^{-3} in Farm Type 1 and US$ 0.04 m^{-3} in Farm Type 3. Farm Types 2 and 4 remained profitable even beyond a water price of US$ 0.1 m^{-3}. The differences in response to pricing of water between farm types were explained by the changes in land use in relation to options that farm types had. The gross sown area[††] decreased drastically with water pricing in Farm Types 1 and 3 but not in Farm Types 2 and 4 (Table 6).

In Farm Type 1, the model results showed no change in land use up to a water price of US$ 0.02 m^{-3} (Table 6) and the profit reduction was only due the additional water cost (Figure. 3). At a water price of US$ 0.03 m^{-3}, less area under Kharif rice was selected (0.22 ha against 4.4 ha in the base run), and less Pishanam rice (0.08 ha against 4.4 ha). An equal area of lowland banana was selected (0.6 ha) up to a water price of US$ 0.1 m^{-3}. Vegetables were selected up to the water price that these land use options remained profitable; up to US$ 0.04 to US$ 0.1 m^{-3} depending on the profitability and water requirement of a particular vegetable type (Table 6).

In Farm Type 2, area under Kharif rice was drastically less selected by the model (0.09 ha in stead of 2.78 ha) and was replaced by less water demanding green gram at a water price of US$ 0.01 m^{-3}. Kharif rice was cultivated mostly using water from canal and well which was now priced in these model runs. An equal area under Pishanam rice was selected even up to a water price of US$ 0.1 m^{-3} since it was cultivated using the monsoon rainfall and little water was used from canal and well. Above US$ 0.01 m^{-3} of water and for every cent increase the water use remained unchanged and water cost increased linearly with water price (Figure. 3).

[††] Gross sown area is the cumulative land area used to cultivate crops in a year. Two crops in the same piece of land were added to get the gross sown area.

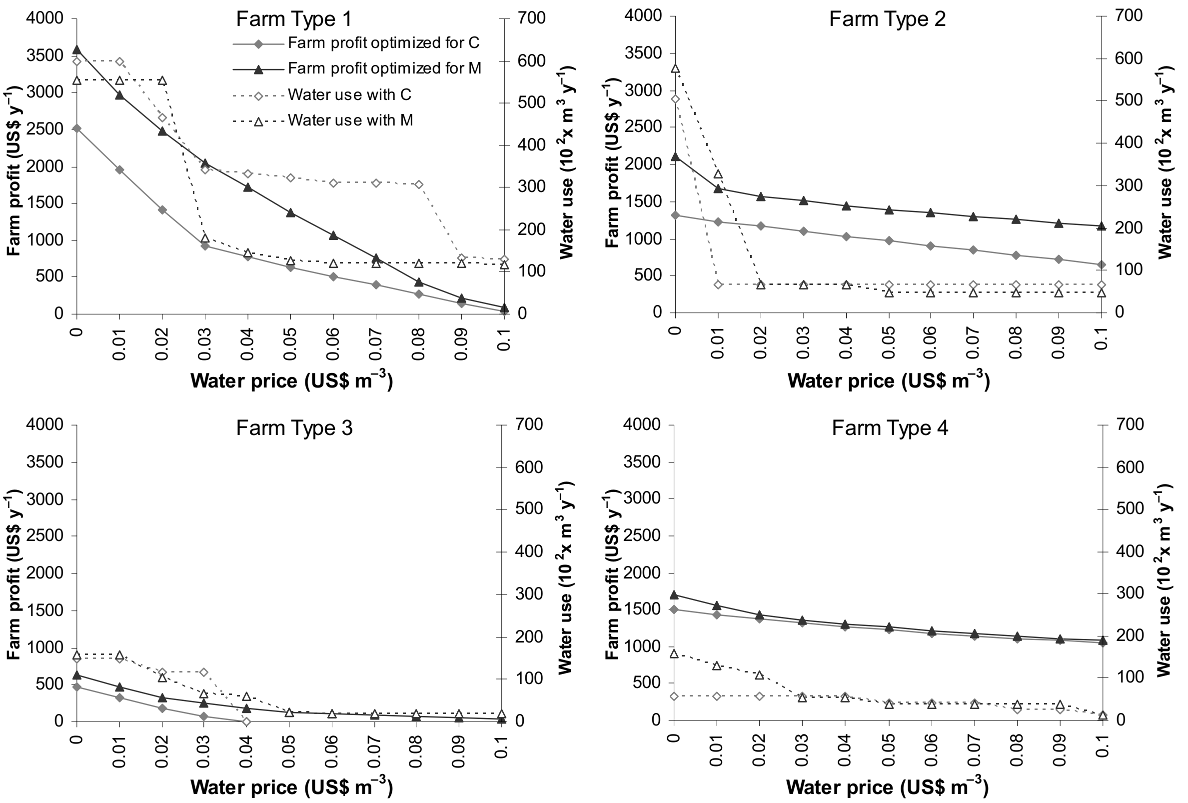

Figure. 2. Optimized farm profit and corresponding water use for the selected land use for different water pricing under conventional (C) and modified (M) rice cultivation.

In Farm Type 3, half of the available land was allocated to cultivate banana and the remaining half to rice in both Kharif and Pishanam season up to a water price of US$ 0.01 m^{-3}. At a price of US$ 0.02 m^{-3}, less area was allocated to Kharif rice (0.04 ha compared to 0.5 ha in the base run) just to meet family food requirements. The profits declined steadily with increasing water price up to US$ 0.03 m^{-3} and became zero at higher water price.

In Farm Type 4, allocation of land use did not change for water prices from US$ 0.01 to 0.04 m^{-3} (Table 6). Water available from well and rainfed tank was very low and crops were cultivated mostly using rainfall in this farm type. This did not lead to dramatic change in land use or drop in farm profit when running the model with different levels of water price (Figure. 3). Above US$ 0.05 m^{-3} of water, land use selected shifted from black gram to sesame and the area under vegetables was halved.

The labour use and labour cost for the selected land uses at different water prices are plotted in Figure. 4. In Farm Types 1, 2 and 3, hired women labour was related to the cultivation of rice and hired men labour to banana. When rice was not selected, the corresponding labour requirement for women also reduced, showing the link in the model between rice cultivation and provision of employment to women.

Table 6. Model-optimized land use (ha) under different water pricing[1] for conventional rice cultivation in all four farm types.

a) Farm Type 1

Crop activities (ha)	Water price (US$ m^{-3})*					
	0	0.03	0.04	0.05	0.06	0.1
Kharif rice	4.40	0.22	0.22	0.22	0.08	0.08
Pishanam rice	4.40	0.08	0.08	0.08	0.08	0.08
Pishanam rice (WI)	0	0.16	0	0	0	0
Banana	0.60	0.60	0.60	0.60	0.60	0.60
Banana (WI)	0.20	0.21	0	0	0	0
Ladiesfinger_1	0.20	0.20	0.20	0	0	0
Ladiesfinger_2	0.20	0.20	0.20	0.20	0.20	0.20
Tuber	0.20	0.20	0.20	0.20	0.20	0
Brinjal_Clusterbean#	0.20	0.03	0	0	0	0
Gross sown area	*10.40*	*1.90*	*1.50*	*1.30*	*1.16*	*0.96*

b) Farm Type 2

Crop activities (ha)	Water price (US$ m^{-3})*		
	0	0.01	0.1
Kharif rice	2.78	0.09	0.09
Phisanam rice	2.78	2.78	2.78
Green gram	0.22	2.91	2.91
Gross sown area	*5.78*	*5.78*	*5.78*

c) Farm Type 3

Crop activities (ha)	Water price (US$ m^{-3})*		
	0	0.02	0.04
Kharif rice	0.50	0.04	0
Pishanam rice	0.46	0.46	0
Banana	0.50	0.50	0
Gross sown area	*1.46*	*1.00*	*0*

d) Farm Type 4

Crop activities (ha)	Water price (US$ m^{-3})*				
	0	0.05	0.07	0.08	0.1
Pishanam rice	0.19	0.19	0.19	0.10	0.10
Tomato	0.20	0.20	0.20	0.10	0.10
Gherkin	0.20	0.20	0.20	0.10	0
Onion	0.20	0.20	0.20	0.20	0
Green gram	2.80	2.80	2.80	2.90	2.90
Black gram	1.97	0.20	0.20	0.20	0.10
Sesame	0.83	2.60	2.44	2.61	2.90
Blackgram_Sesame#	0	0	0.08	0.04	0
Gross sown area	*6.39*	*6.39*	*6.31*	*6.25*	*6.10*

[1]Data are presented for the water price at which the land use changes; *Water use from all resources (excluding rainfall) priced at same price; #Intercrop; WI = Well irrigated; All rice crops have 0.08 ha ha^{-1} of rice nursery area per hectare rice selected; 0 = crop activity not selected. Gross sown area is the cumulative land area used to cultivate crops in a year. Two crops on the same piece of land were added to get the gross sown area.

In Farm Type 4, the proportion of area under rice was only 6%, therefore the effect of the relationship between rice cultivation and womens' labour was very small (Figure. 4).

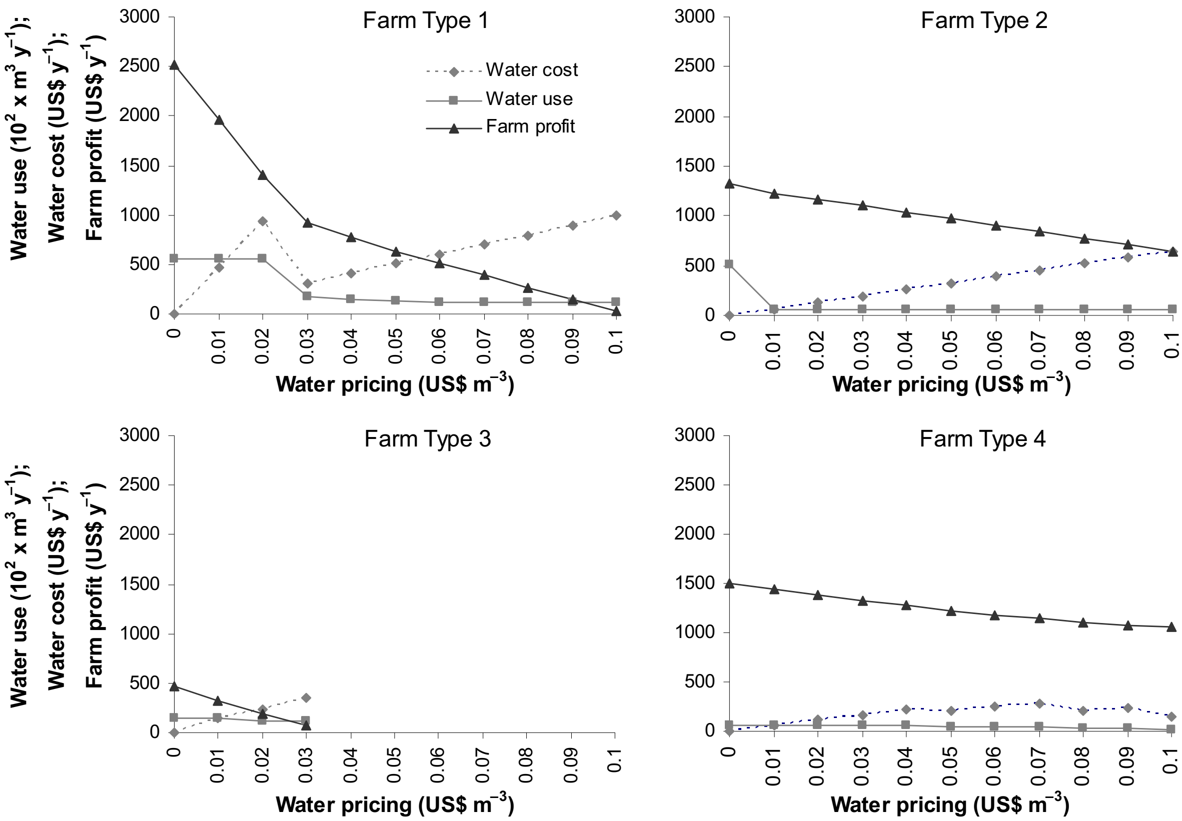

Figure. 3. Total water used, water cost and farm profit for different levels of water pricing, optimized for the current farm practices (base run). For land use see Table 6.

Step 4: Pricing water with modified rice cultivation introduced to the model

Adoption of modified rice cultivation can be an option to maintain farm profit to cope with the increased costs due to water pricing. The model results showed that the level of water pricing at which the same profit was achieved by adopting modified rice cultivation varied among the four farm types (Figure. 2).

In Farm Type 1, a profit of US$ 2500 y^{-1} was calculated when conventional rice cultivation was the only option and when water was not priced. An equal profit could be obtained at a water price of US$ 0.02 m^{-3} when modified rice cultivation including water-saving irrigation is an option. This value was US$ 0.06 m^{-3} for Farm Type 2 and US$ 0.01 m^{-3} for Farm Types 3 and 4 (Figure. 2). Without water pricing, the combination of modified planting, conventional irrigation, mechanical weeding and organic manure application was selected in all four farm types as this combination gave the highest yield. In Kharif rice cultivation, the conventional irrigation was replaced by water-saving irrigation at a water price of US$ 0.02 m^{-3} in Farm Types 1 and 3 and at US$ 0.01 m^{-3} in Farm Type 2 (Table 7). In Pishanam rice cultivation, water-saving irrigation was selected at a water price of US$ 0.03, 0.05, 0.02 and 0.01 m^{-3} in Farm Types 1 to 4, respectively. The differences between the two seasons reflect the differences in canal and well water use in all farm types. Farmers mostly used the monsoon rainfall in the Pishanam season with canal and well water for supplemental irrigation, while the major share of irrigation water came from canal and well with little rainfall in the Kharif season.

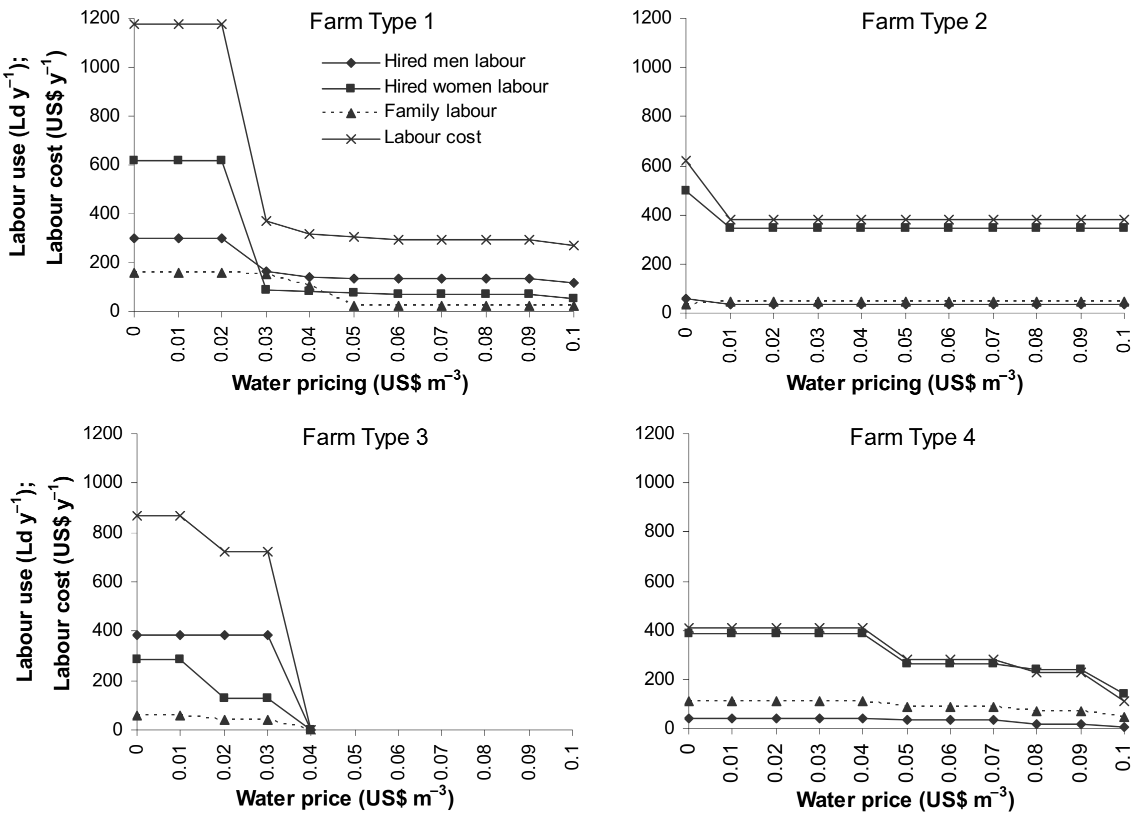

Figure. 4. Labour use (Labour days y^{-1}) and labour cost (US$ y^{-1}) for the selected land use for different levels of water pricing under current farm practices (base run). For land use see Table 6.

Selection of modified rice cultivation as a land use helped rice crops to remain profitable under higher water pricing (Tables 6 and 7). In Farm Type 1, the area under both Kharif and Pishanam rice that was selected was 4.4 ha up to a water price of US$ 0.08 m^{-3} when modified rice cultivation was introduced as an option (Table 7), while the area was lower, 0.22 and 0.08 ha for Kharif and Pishanam rice respectively, at a water price of only US$ 0.03 m^{-3} when conventional rice cultivation was the only option (Table 6). Modified rice cultivation was selected only up to a water price of

US$ 0.01 m^{-3} in the Kharif season in Farm Type 2 and in the Phisanam season in Farm Type 4. The area under Pishanam rice remained unaffected either with modified or conventional rice cultivation even above a water price of US$ 0.1 m^{-3} in Farm Type 2.

In Farm Type 3, the area under rice increased from 0.5 ha to 0.74 ha in the Kharif season and from 0.46 ha to 0.68 ha in the Pishanam season when water-saving irrigation (I_2) was offered as a land use option. This was at the cost of the area under banana. The Kharif rice area further increased to 1 ha at a water price of US$ 0.03 and 0.04 m^{-3} and beyond this price the area dropped to 0.04 ha, while Pishanam rice area increased to 0.93 ha and was maintained even beyond US$ 0.1 m^{-3} (Table 7). However, the profit was reduced proportionally to the water price (Figure. 2). Including modified rice cultivation kept the farm profit positive in Farm Type 3 even at a water price of US$ 0.1 m^{-3} whilst the profit became zero or negative at a water price of US$ 0.04 m^{-3} when only conventional rice cultivation was an option (Figure. 2). At higher water pricing, a combination of conventional planting, water-saving irrigation, mechanical weeding with conventional nutrient management was selected ($P_1I_2W_2N_1$) since conventional planting required less water than modified planting due to the longer field duration of the latter practice.

Step 5: Pricing water with modified rice cultivation and water quotas

Providing a water quota could be a means to protect the farmers with little resources and low farm profit, but should not prohibit the adoption of water-saving irrigation in rice. It could serve to meet the objectives of both farmers and the society at large, i.e. improving the resource use efficiencies without jeopardizing the farmers' livelihoods.

In Farm Type 1, water-saving irrigation was selected at a water price of US$ 0.02 m^{-3} in Kharif rice and US$ 0.03 m^{-3} in Phisanam rice and this remained unchanged for any water quota from 0 to 10,000 m^3 y^{-1}. Providing water quota did not mitigate the effect of water pricing; increasing water prices and water quota continued to decrease profit in this Farm Type (Figure. 5). Water quota of 1000 to 10,000 m^3 y^{-1} was very little as in this Farm Type 1 nearly 60,000 m^3 of water per year is used to cultivate 6 ha of land (Figure. 2). Water quotas did mitigate the effect of water pricing in Farm Types 2, 3 and 4 since farm profit was maintained at different levels of water pricing if water quota was introduced (Figure. 5).

In Farm Type 2, water-saving irrigation was selected at a water price of US$ 0.02 m^{-3} in Kharif rice and remained unchanged up to a water quota of 10,000 m^3 y^{-1}. Pishanam rice was cultivated mostly using rainfall and water-saving irrigation was selected only in parts of the rice area at a water price of US$ 0.05 m^{-3} (Table 7). Moreover, this partial selection of water-saving irrigation was continued from a water

Table 7. Model-optimized land use (ha) under different water pricing[1] after the introduction of modified rice cultivation in all four farm types.

a) Farm Type 1

Crop activities (ha)	Water price (US$ m^{-3})*								
	0	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.1
Kharif rice	[a]4.40	[b]4.40	[c]4.40	4.40	4.40	4.40	4.40	0.54	0.54
Pishanam rice	[a]4.40	4.40	[b]4.40	4.40	4.40	[c]4.40	4.40	0.08	0.08
Pishanam rice (WI)	[a]0.19	0.19	0.40	0.54	[b]0.60	0.60	0.80	0.80	[c]0.80
Banana	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Banana (WI)	0.21	0.21	0	0	0	0	0	0	0
Ladiesfinger_1	0.20	0.20	0.20	0.06	0	0	0	0	0
Ladiesfinger_2	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Tuber	0.20	0.20	0.20	0.20	0.20	0.20	0	0	0
Gross sown area	*10.40*	*10.40*	*10.40*	*10.40*	*10.40*	*10.40*	*10.40*	*2.22*	*2.22*

b) Farm Type 2

Crop activities (ha)	Water price (US$ m^{-3})*					
	0	0.01	0.02	0.03	0.05	0.1
Kharif rice	[a]2.78	[b]2.78	0.09	[c]0.09	0.09	0.09
Pishanam rice	[a]2.78	2.78	2.78	2.78	[a,b]2.78	2.78
Green gram	0.22	0.22	2.91	2.91	2.91	2.91
Gross sown area	*5.78*	*5.78*	*5.78*	*5.78*	*5.78*	*5.78*

c) Farm Type 3

Crop activities (ha)	Water price (US$ m^{-3})*						
	0	0.02	0.03	0.04	0.05	0.06	0.1
Kharif rice	[a]0.50	[b]0.74	1.00	[c]1.00	0.04	0.04	0.04
Pishanam rice	[a]0.46	[a,b]0.68	[b]0.93	0.93	0.93	[c]0.93	0.93
Banana	0.50	0.26	0	0	0	0	0
Gross sown area	*1.46*	*1.68*	*1.93*	*1.93*	*0.97*	*0.97*	*0.97*

d) Farm Type 4

Crop activities (ha)	Water price (US$ m^{-3})*						
	0	0.01	0.03	0.04	0.05	0.07	0.1
Phisanam rice	[a]2.78	[a,b]2.78	0.18	[b]0.19	0.19	0.19	0.10
Tomato	0.20	0.20	0.20	0.20	0.20	0.20	0.10
Gherkin	0.20	0.20	0.20	0.20	0.20	0.20	0
Onion	0.20	0.20	0.20	0.20	0.20	0.20	0
Green gram	0	0	2.80	2.80	2.80	2.80	2.90
Black gram	1.97	1.97	1.97	1.97	0.20	0.20	0.10
Sesame	0.83	0.83	0.83	0.83	2.60	2.44	2.90
Black gram_Sesame#	0	0	0	0	0	0.08	0
Gross sown area	*6.18*	*6.18*	*6.38*	*6.39*	*6.39*	*6.31*	*6.10*

[1]Data are presented for the water price at which the land use changes; * Water use from all resources (excluding rainfall) priced at same price; #Intercrop; All rice crops have 0.08 ha ha^{-1} of rice nursery area per hectare rice selected; [a] This point onwards $P_2I_1W_2N_2$ combination; [b] This point onwards $P_2I_2W_2N_2$ combination; [c] This point onwards $P_1I_2W_2N_1$ combination; 0 = crop activity not selected. Gross sown area is the cumulative land area used to cultivate crops in a year. Two crops on the same piece of land were added to get the gross sown area.

quota of 0 to only 6000 m^3 y^{-1}. Water-saving irrigation was not selected if more than 6000 m^3 y^{-1} of water as quota was given free of cost even at a water price of US$ 0.1 m^{-3}. Only water-saving irrigation in Kharif rice was selected at a water price of US$ 0.01 m^{-3}. Hence, impact of levels of water pricing and quota differ per season. No water quota was required for this farm type to keep the profit above US$ 1600 y^{-1} with the selection of water-saving irrigation in Kharif rice at a water price of US$ 0.01 m^{-3} (Figure. 5). Water quota of 5000 m^3 y^{-1} maintained the profit above US$ 1600 y^{-1} even at a water price of US$ 0.1 m^{-3}.

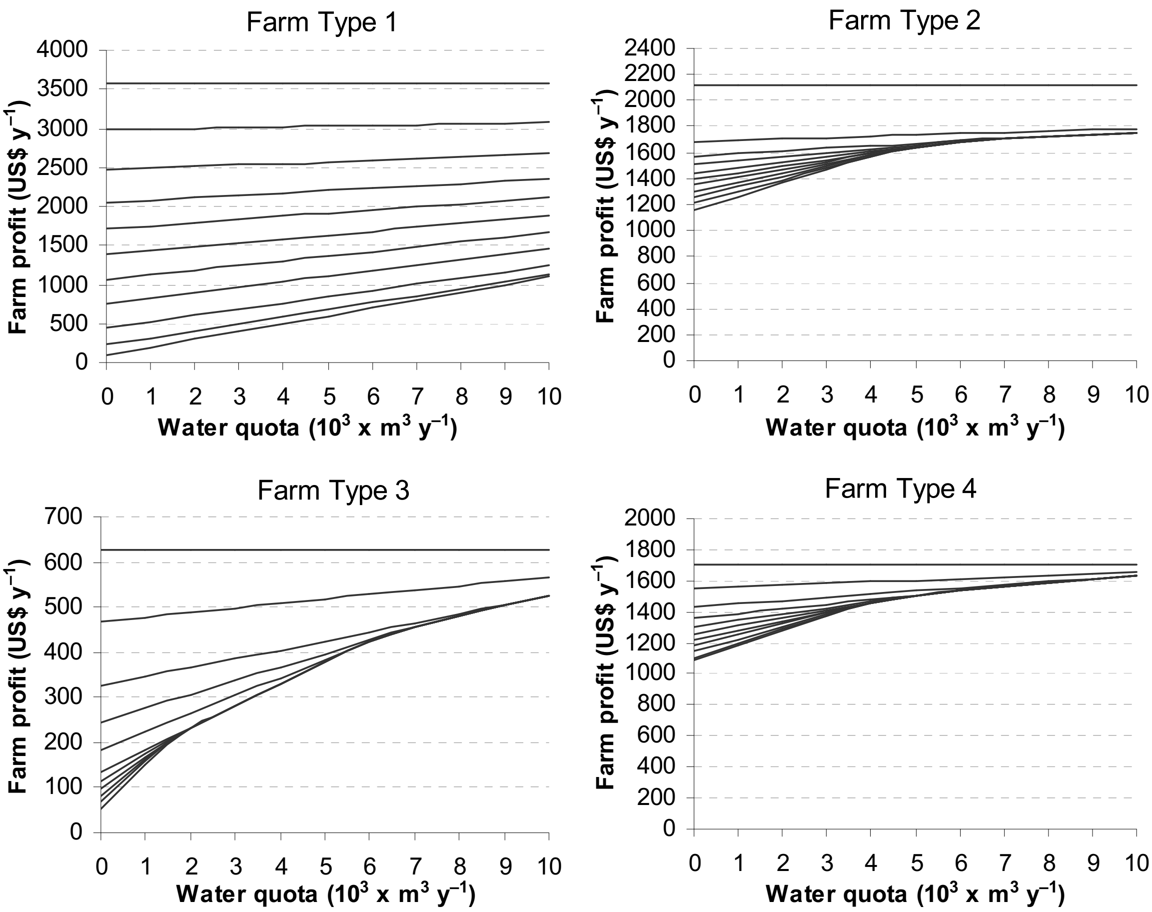

Figure. 5. Model-optimized farm profit for different water pricing and water quota levels with the introduction of modified rice cultivation. The lines are per water pricing level starting from US$ 0 to US$ 0.1 m^{-3} of water at an increment of US$ 0.01 from top to bottom, respectively. Water quota is the quantity of water available to a farmer free of cost and excess water used was priced as normal.

In Farm Type 3, water-saving irrigation was selected if the water price became US$ 0.02 m^{-3} in both Kharif and Pishanam rice and this remained unchanged for any water quota from 0 to 10,000 m^3 y^{-1}, but the optimized profit with modified rice cultivation was reduced from 625 to 325 US$ y^{-1} (Figure. 5). Farmers of this farm type are the poorest among the four farm types, with an observed farm profit of only US$ 146 y^{-1}.

Model results showed that water quota of 4000 and 9000 $m^3 y^{-1}$ could mitigate the effect of water pricing and keep profit above US$ 400 y^{-1} and US$ 500 y^{-1}, respectively, at a water price of US$ 0.02 m^{-3} with the adoption of water-saving irrigation in rice in both seasons (Figure. 5).

In Farm Type 4, water-saving irrigation was selected at a water price of US$ 0.01 m^{-3} in the only Pishanam rice and remained unchanged up to a water quota of 10,000 $m^3 y^{-1}$. At this water pricing, the farm profit was above US$ 1500 y^{-1} which was well above the observed US$ 305 y^{-1} and the optimized farm profit of US$ 1494 y^{-1} with no water quota. A water quota of 6000 $m^3 y^{-1}$ gave a same profit even at a water price of US$ 0.1 m^{-3}. There was a large difference in the farm profit between observed and optimized for current farm practices showing the potential to increase profit even without the introduction of modified rice cultivation in this farm type.

Adoption of water-saving irrigation only in part of the Pishanam rice area in Farm Types 2, 3 and 4 was due to the intensive monsoon rainfall, however, the percentage of Pishanam rice area with adoption of water-saving irrigation increased with increasing water price (data not presented).

4. Discussion

4.1. Validity of the model

The model can be partially falsified by comparing observed values with the model outcome for the objective function (e.g. farm profit) and the selected land use. There are, however, several reasons why model results are different from those observed. The differences could be attributed to: 1) differences between observed and virtual farms as created for model analysis; 2) sub-optimal land use choices by the farmers are not necessary far from the optimized ones in achieving objectives; and 3) sensitivity of the model on the limits set to specific constraints i.e. high valued crops such as banana and vegetables. In the following discussion these points are elaborated.

Virtual farms per farm type were defined in order to eliminate the effect of specific farmers' preferences and skills in crop management. In this process, we eliminated some profitable crop options such as rose and rice for seed production as these activities were specific to a single farm, but income of these crops are important in the calculation of the average observed income.

Currently farmers may not use their land in an "economically optimal" way as in the sense of the model output. The difference between observed and model values may be caused by a lack of economic awareness, as the majority of the farmers do not keep records of their farming activities. Farmers' decisions on land use, on the other hand, are based on more than economic benefit. Resource availability, anticipated climatic and market conditions, previous experience and family requirements, all may explain the economically sub-optimal land use observed in reality as compared with the model. For example, in the optimization for Farm Types 2 and 4 under current practices, not all the observed cropping activities were chosen in the optimized land use (Table 4), which indicates that the land use choices by the farmers were not optimal from the perspective of the model. The model optimization process looked for the best possible options to maximize farm profit in a mathematical sense, but economically sub-optimal land use activities may have better suited the farmers' conditions. In Farm Type 1, all crop options except tomato (Table 4) were selected in the optimized land use showing that these farmers were close to the optimal land use to achieve maximum profit. Farmers of Farm Type 1 were better educated than farmers from the other three farm types (Senthilkumar et al., submitted-a), and the high farm resource endowments and education level of the farmers may play a role in improving farmers' decisions on land use. Among the Farm Types 1, 2 and 3, farmers of Farm Type 1 hired more labourers but used less labour per ha land than the other farm types. They owned machines which reduced the costs of cultivation while other farmers had to pay for hiring machines (Senthilkumar et al., submitted-a).

The model results were very sensitive to some specific constraints (Table 3). The maximum land area for banana and vegetables were limited *a priori* and the maximum allowed area of these crops was selected in all runs as they were more profitable than the other crops. Any change in the limits set to these constraints will affect the model outcome. In reality, farmers cannot produce only banana and vegetables as market price for these crops may fall due to distortion of the relationship between supply and demand which in turn will reduce the profitability. In general, exogenous factors to the farms acting at higher levels but influencing farmer decisions can be taken into account if the modeling approach also addresses higher levels and feedbacks to the lower, farm level (Kruseman et al., 1995; Kruseman and Bade, 1998; Laborte et al., 2006). In addition, cultivation of high value crops such as banana and vegetables requires high capital investment and is associated with risk which will influence the farmers' decisions. The constraint on rice for food self sufficiency may not be applicable when rice cultivation becomes unprofitable due to water pricing. The farmers may buy cheap rice in the market rather than cultivating their own rice.

Even with all these drawbacks, this model for analysis of farms helped to identify the opportunities available in a farm type and to distinguish between farms in their options for improvement. The model results indicate possible changes and directions of change, although the absolute values calculated may be less reliable.

4.2. Model results on technology adoption and policy intervention

When the modified rice cultivation practices were available for selection by the model, it selected a combination of modified planting, mechanical weeding, organic manure application with conventional irrigation ($P_2I_1W_2N_2$). Water saving irrigation was not selected since water is not priced at the moment and the combination of $P_2I_1W_2N_2$ gave a higher yield than any other combination. Farmers have no incentives to adopting water saving irrigation since water is free of costs. Evidently, imposing water prices forced the model to select water saving irrigation as this resulted in saving water costs for rice production to compensate for losses in profit. The water price, however, at which the water-saving irrigation was selected, varied across farm types and seasons. These differences were due to the quantity of water used from canals and wells, and the productivity of the rice crops. A combination of modified rice cultivation and water pricing policies was effective in achieving the objectives of both farms and the society at large, i.e. improving the water use efficiency of the region without reducing the farmers' income.

The model results showed that the poor farmers of Farm Type 3 can achieve higher profits than those currently observed with the introduction of modified rice cultivation and water pricing policies. Considering the low resource endowments of these farmers and the resulting very low observed farm profit (US\$ 146 y^{-1}), water quota policies can be introduced to protect these farmers. However, water quotas should not hinder the farmer from adopting water-saving irrigation. Through this analysis the possible range of water pricing and water quota at which adoption of water saving irrigation and farm profit is improved or guaranteed was identified for this group of poor farmers.

4.3. Changing policies – A reality?

The model results can be used to advise on policies and instruments that could be used but the question remains whether such advice will be accepted given the current political setting.

Water pricing and water quota policy measures compel farmers to adopt water-saving irrigation. The model results are promising in that adoption of water-saving irrigation was possible in all four farm types through water pricing while maintaining farm profit above that observed with current farm practices. Forcing the farmers to adopt water-saving irrigation will enhance the water productivity of the region and thus make more water available for water-scarce areas and for users beyond agriculture. However, imposing water pricing policies depend on the decisions of policy makers. It may not be possible for them to keep themselves in power after implementing water pricing policies. Courageous policy decisions need to be taken to achieve the objectives of farmer and the society in the long run. Moreover, implementation of water pricing apparatus might incur too high costs of operations, and pricing water could create socio-political unrest in the region. More insight is needed on the cost effectiveness of implementing the water pricing and water quota systems. The analysis of implications of such a system in operations could be studied on a small scale before designing the system for the state. However, pricing electricity for pumping well water is already practiced in some parts of India (e.g. the state of Gujarat) and experiences could be gained from there.

Not only forcing by pricing and quota policies need to be considered in adoption of water-saving irrigation. Farmers face problems in regulating their water use. The cascade system of irrigation, uncertainty about the timing and amount of water release for irrigation, inability of the farmers to adopt water-saving irrigation when the surrounding farmers flooded their fields and flooding of rice fields during the monsoon season could all hamper effective implementation (Senthilkumar et al., 2008). The problems with other components of the modified rice cultivation such as higher labour requirement for modified planting during the peak labour demanding period in the entire region, difficulties in preparing modified nursery beds, scarcity of organic manures (Senthilkumar et al., 2008; Senthilkumar et al., submitted-a) remain to be resolved as well. Policy interventions through other instruments as development of irrigation infrastructure, organising cooperative management of resources and training and education in modified rice cultivation practices could all have additional impact on the adoption of modified rice cultivation. Model analysis, though not the MGLP model used here, could be used to evaluate some of the above policy instruments. Model analysis on development of irrigation infrastructure to improve water productivity at regional scale was reported for the north of India (van Dam et al., 2006). Co-operative management of resources could be mimicked in MGLP models by bringing many small farms together and generating resource use coefficients for large farms. Resource use efficiencies were high at larger operational scales and *vice versa* (Senthilkumar et al., submitted-b). Training and education in modified rice cultivation practices, the resulting skills of the farmers, and ensuring benefits cannot be studied using the type of model described here.

5. Conclusions

Opportunities exist to increase farm profit even without the introduction of modified rice cultivation, by selecting the optimal land use in all four farm types. The impact differed between farm types based on their resource endowments and other characteristics. Adoption of modified rice cultivation further increased farm profit, where the level of impact depended on the percentage of area under rice cultivation in each farm type. With the introduction of modified rice cultivation and optimal land use, the objective of the farmers, i.e. increasing farm profit, can be achieved. To increase the use efficiencies of the commonly available water resources for the benefit of society at large, water pricing policies could be imposed by the government. The combination of adopting modified rice cultivation and government policies on water pricing and water quota will enhance the water use efficiency of water use of the region. Water quotas would be needed for low resource endowed farmers to overcome the negative effect of water pricing policies on their income. Apart from government water pricing and quotas, policies should also address training and education in modified rice cultivation practices, development of irrigation infrastructure and organised cooperative management of commonly available water resources. The model gives insight on the impact of modified rice cultivation and water pricing policies on adoption of water-saving irrigation and indicates possible changes and the direction of change. However, absolute values should be used with caution because a number of crucial factors have not been explicitly accounted for in the model.

Acknowledgement

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Chapter 6

General discussion†

† Parts of this chapter were presented in:

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1. Modify rice cultivation to save water?

Water is becoming a scarce resource in the state of Tamil Nadu, India. The per capita availability of water is reduced due to growing population and diminishing water resources. Water required for domestic and industrial purposes is growing and the current share of 15% is expected to increase to 25% in 2025. It is estimated that the water supply-demand gap for irrigated crops will be 21 billion m^3 in 2025 (Palanisamy and Paramasivam, 2000). Hence, there is an urgent need to save water to fill the gap between growing demand and diminishing resources.

Rice is the predominant crop cultivated in the state and it consumes 70% of water available for agriculture. It is the most water-consuming crop as it requires 1500 mm of water per crop. The area under rice, however, cannot be reduced as rice is the staple food and demand for rice continues to increase. To sustain the present food self-sufficiency and to meet future food requirements, India has to realise an annual growth in rice production of at least 3% (Thiyagarajan and Selvaraju, 2001).

The problem of water scarcity and inefficient use of water in rice raised the question, is there any possibility to reduce water use in rice with no penalty on yield? The search for water-saving practices during the 1970s and 1980s was discouraged, as reductions in water input during cultivation led to proportional yield reductions, primarily caused by heavy weed infestation (De Datta, 1981). Current pressure on water resources have led to more structural research in developing cultivation practices that save water and increase water productivity (Bouman and Tuong, 2001).

The proportional decrease in yield in response to reducing water supply suggests that various management practices should be changed simultaneously in order to enhance water productivity, without reducing the productivity of other factors, primarily land (i.e. yield), labour and fertilizer (Bindraban et al., 2006). The System of Rice Intensification (SRI) (see Chapter 2 for details) is an approach introduced in many rice growing countries in Asia and beyond that combines several practices of rice cultivation modified simultaneously and that increased the rice yields while saving water (Stoop et al., 2002). We adopted some of the management practices of SRI, while other practices were adapted to the local conditions and named it “modified rice cultivation”. The reason behind not classifying this modified rice cultivation as SRI are as follows: SRI methods were originally developed as “best practices” specifically intended to raise yields of smallholder farmers who do not benefit from the “green revolution”, i.e. those farmers who cannot use improved varieties and purchased external inputs as mineral fertilizers and chemicals for crop protection (Uphoff et al., 2008). There is much controversy about “defining” the SRI practices. Proponents (Stoop et al., 2002; Uphoff, 2002; Stoop and Kassam, 2005) did not accept results of experiments (Sheehy et al., 2004; Sinclair and Cassman, 2004; Sheehy et al., 2005), if any modification was made, or if a single component practice of SRI was omitted in the trials. These controversies still continue in the recent papers of proponents (Uphoff et al., 2008) and opponents (Latif et al., 2005; McDonald et al., 2006).

2. Achievements and problems with adoption of modified rice cultivation

Through our on-station experiments (Chapter 2), we found a technical solution to save water without jeopardising productivity. A combination of modified planting, water-saving irrigation, mechanical weeding, and green manure application saved 40 – 50 % of the irrigation water even with higher yields compared with conventional rice cultivation (Senthilkumar et al., 2008). Saving on irrigation water in rice production with no effect on yields has been reported by others: Bindraban et al. (2006) reported water savings up to 50% without penalty on yield for a range of experimental conditions. Sandhu et al. (1980) and Li et al. (2005) found no adverse effects on rice yields with intermittent irrigation at 1 to 5 days after disappearance of standing water which saved 25 to 50% water compared with continuous submergence. Purushothaman and Jeyaraman (1992) observed similar yields with partial submergence of rice fields at critical stages of growth compared with continuous submergence. The saving of 40 and 50% of the water with water-saving irrigation in our on-station experiments needs further scrutiny as we did not measure the depth of the ground water table in the experimental fields. Extremely shallow water tables of 10 – 40 cm can reduce the required water inputs by 15 – 30% without a significant impact on yield (Belder et al., 2005; Bouman et al., 2007). However, ground water tables will be in general not as shallow in many parts of the state and depth will only increase in future (Seckler et al., 1999) given the increasing demand. Modified rice cultivation has the potential to save water without reducing, or even increasing rice yields.

The results of the two farm surveys highlighted the pros and cons of the modified rice cultivation. The farmers were positive on the yield advantages in modified rice cultivation; however, adoption of modified rice cultivation remained low due to the increased labour demand for modified planting, unwillingness of agricultural labourers to change practices in general, difficulties with modified nursery preparation and the need to replace cheap womens' labour for hand weeding with more costly mens' labour for mechanical weeding. Incentives of farmers to adopt water-saving irrigation remained low as they had enough water in the rice growing seasons at free cost. Moreover, practical difficulties in applying water-saving irrigation such as poor irrigation infrastructure and the resultant unwanted flooding, did not contribute to changing farmers opinions to adopt water-saving irrigation.

The possible solutions to alleviate the problems hindering the adoption of modified rice cultivation are: 1) mechanizing rice transplanting: introducing planting machines which suit the modified rice cultivation. Planting machines were in use by some of the larger farmers and could be made available to all the rice farmers at an affordable price. This will eliminate the problem of higher labour requirement in modified planting, however, it may create unemployment for women labourers as they were engaged in most field operations of rice cultivation; 2) modifications in mechanical weeders: the heavy weighing cono weeder can be altered, thus allowing the women labourers to operate with ease; 3) co-operative rearing of rice seedlings in modified nurseries; and 4) application of water saving irrigation in clusters of fields or at entire village level. Some of the above mentioned options were already put into effect by farmers in some regions (Thiyagarajan, T.M. personal communication).

Currently the modified rice cultivation is being promoted by the state government at a fast rate by diverting available human and capital resources (Thiyagarajan, T.M. personal communication). Farmers were willing to participate in the modified rice cultivation trials; however, the true adoption of the technology can be assessed only after withdrawing the input subsidies such as free seeds and fertilizers to carry out the demonstration trials. Moreover, the demonstration trials are taking place only in a small proportion of the rice area.

3. Is farm typology useful?

Creating farm typologies is a means of categorizing farms, where farm types are inferred from farm characteristics, often using multivariate analysis and clustering techniques (Duvernoy, 2000). Although there were broader classifications of farm production systems in Tamil Nadu (see Chapter 1), no detailed classification of any farming system was attempted based on farmer resource endowments and farm characteristics, and the first attempt was made in this study. We classified the rice-based farms into four farm types using 23 farmer resource endowment and farm characteristics with principal component analysis (PCA) (Chapter 2). The classification was useful in understanding the differences across rice-based farms and to target potential options to save water to appropriate farm types.

The four farm types identified were different in farm size, farm family characteristics, labour use, livestock possession, farm mechanization and available irrigation sources (Table 1 of Chapter 2). Apart from the farmer resource endowments and farm characteristics, location of a farm within a river basin influenced the farm classification (Figure.1 in Chapter 3). The representative farms per farm type were situated together showing the regional similarity in resource endowments and characteristics. In Thamirabarani river basin, among the farm types which received canal water for irrigation., i.e. Farm Types 1, 2 and 3, the large farms (Farm Type 1) were situated at head end of the river basin closer to the reservoirs followed by the medium sized farms (Farm Type 2) and the small farms (Farm Type 3) which were closer to the tail end. Distance from the reservoirs may have an impact on the water availability and profitability of a farm. The farms of Farm Type 4 were situated away from the main irrigation systems and thus did not receive canal water.

4. Importance of farming for farmers' livelihoods

The reliance on farming for family food security varied greatly among these farm types. The wealthier Farm Type 1 used only 14% of the value of crop produce for home consumption. This was 52% in Farm Type 2 and around 75% in Farm Types 3 and 4, showing that the farmers' dependence on farming for their livelihood increased with decreasing resource endowments. Income earned through off-farm employment was above 50% in all four farm types (Table 2 in Chapter 2), implying that farmers cannot completely rely on farming for their livelihood. This could indicate that farmers are moving towards more profitable off-farm employment rather than trying to keep employment in agriculture. A recent survey by the National Sample Survey Organization (NSSO) revealed that nearly 40% of farmers would like to quit farming, if they have the option to do so (Swaminathan, 2006). The average farm size is becoming smaller each year and the cost-risk-return structure of farming is becoming adverse resulting in farmers being increasingly indebted (Swaminathan, 2006). Farmers' education, skills, awareness and availability of capital for investment may have an important role in generating off-farm income. This was reflected on the off-farm income earned per day of labour invested which was much higher in the highly educated, wealthy farms of Farm Type 1 than in the other three farm types (Figure. 6 in Chapter 2).

The role of livestock in income generation was restricted in all four farm types and was only less than 5% of the total income (Table 2 in Chapter 3). In these rice-based farms, animals were kept to meet the family food requirements such as for milk, egg and meat. Livestock is rarely kept as a commercial enterprise. Illegal encroachment of commonly available grazing land reduced the opportunities of rearing animals, i.e. the reason mentioned by the farmers during the farm surveys not to keep livestock. Animals were herded during the lean season and were taken far away from the homesteads in search of new grazing land and in the nearby forest area.

5. Resource use efficiency

Differences in resource use efficiencies of water, labour, capital and nutrients were observed among the four farm types. Rice was the most important crop and its resource use efficiencies determined the farm level efficiencies in all four farm types, followed by banana in the first three farm types. Differences in water use and water productivity in rice were also observed in all four farm types (Table 5 in Chapter 4). Typically, total water input in rice fields varied between 500 and 3000 mm depending on the environmental conditions and the length of the growing period (Bouman and Tuong, 2001). In this study, the observed water use in rice was between 830 and 1450 mm across the four farm types (Table 5 in Chapter 4). However, in our study only the water inflow through irrigation water and rainfall was measured. We did not consider other flows such as seepage and percolation in and out of the rice fields.

Adoption of water-saving irrigation was hindered since water from canal and well is available free of cost, thus not creating any incentives to the farmers (Chapter 2). However, in Farm Types 2 and 4, some of the farmers were selling excess water available in their wells to the neighbouring farmers who had no wells. Though this practice is illegal, it may lead to more judicious use of well water and can improve the overall water productivity of the region. Among the four rice based farm types, available water resources were more efficiently used in Farm Type 4 than in other farm types. Open access to the commonly available water resources such as canals and system tanks and free electricity to pump the well water led to lowered water productivity in Farm Types 1 and 2.

Low labour productivity, profitability and nutrient use efficiencies were observed in the farms of Farm Type 3 compared with other farm types due to their small operational scale (Figure.1 and 2 in Chapter 4). To enhance the resource use efficiencies of these small farms, co-operative farming by bringing many small farms together may be an option to consider.

6. Policy interventions on resource conservation and protection of farmers' livelihood

Resource conservation is rarely prioritized under conditions of poverty (Maslow, 1943). Farmers tend to maximize economic output of farming activities which may not coincide with the optimal use of resources from an ecological perspective. Since the farmers had no direct say on the timing of release of canal water for irrigation, they therefore used as much water as possible when they had access to it (Chapter 2). Providing canal water free of charge and free electricity to pump well water leads to inefficient water use in rice cultivation. Pricing electricity can be implemented immediately in the state but pricing of canal water is only an option after modernization of irrigation infrastructure. Efficiency can be enhanced by well-chosen combinations of resource efficient technologies at the farm level and policy interventions at regional level, thereby reaching a balance between protecting farmers' livelihoods and resource conservation. Though there are many policy instruments that can be implemented, we studied the impact of policy instruments such as pricing water, rules and regulations of water use, training and education to farmers on resource efficient technologies like modified rice cultivation, irrigation infrastructure development and organised co-operative management of common agricultural resources. Although all the above policy instruments have the potential to enhance the water use efficiency of the region, water pricing policies affect the farm income directly, and rules and regulations on water use restrict the farmers' choices on land use and in turn affect income. The latter three policies can enhance the water use efficiency without affecting the farmers' livelihoods as it had no extra cost to farmers (Table 10 in Chapter 4).

Development of the major irrigation infrastructure such as linking rivers, which is already underway in the state, will increase the water availability. However, considering that 44% of agricultural area is still cultivated under rainfed condition (Table 1 in Chapter 1), and that demand of water for domestic and industrial use will increase from currently 15% to 25% in 2025 (Thiyagarajan et al., 2002), efficient use of the available water resources is imperative to sustain food security. At this point, the findings of this study could help the farmers and policy makers in identifying optimal farming and policy strategies to achieve a balance between resource conservation and protection of farmers' livelihoods.

7. Farm analysis

We analysed the impact of only water pricing and water quota policy instruments on adoption of water-saving irrigation and on farmers' livelihoods. The model analysis gave insight on the impact of adopting modified rice cultivation on farm profit, and how it may help farmers to overcome water pricing policies of the government if implemented. According to the model results, the profit of farmers who cultivate rice conventionally but without water pricing was equal to that of farmers who practice modified rice cultivation with water pricing in all four farm types. However, the level of water pricing at which water-saving adoption would take place to counteract income loss is low and varied across farm types and seasons. Further analysis could be extended to other policy instruments such as irrigation infrastructure development, training and education and co-operative management of common agricultural resources, but not with the model since coefficients that describe impact of these instruments are hard to define and quantify.

Water pricing policy measures are useful merely to put more pressure on the farmers to adopt water-saving irrigation. It will be an unwelcome message for the farmers that may lead to socio-political unrest in the region. Moreover, imposing water pricing policies are linked to the decisions of policy makers. It may not be possible for the politicians to keep themselves in power after implementing water pricing policies. Courageous policy decisions need to be taken to achieve the objectives of farmer and the society in the long run. However, policy measures such as training and education of modified rice cultivation practices, development of irrigation infrastructure and organised co-operative management of commonly available water resources are most likely to be accepted by the farmers and may have impact as well on the adoption of water-saving irrigation in rice (Chapter 5).

In the model analysis, we mainly focused on the adoption of water-saving irrigation in rice with policies on water pricing and water quotas. However, the trade-off between economic and other environmental objectives may become as important in the future political arena. The unexpected effects on environment due to change in land use such as N pollution or N depletion have then to be studied. For this purpose, a first attempt was made to include two other objective functions, i.e. minimization of water use (MINWU; $m^3\ y^{-1}$) and Optimization of partial N balance towards zero (OPTPNB; kg y^{-1}) (see Appendix for the mathematical formulation). Maximizing farm profit is usually the main objective of the farmers. Minimizing water use is an objective for policy makers and the society at large as pressure on water resources increases to meet growing demand. Optimizing N balances are important for the environment and interesting to both the farmers and society at large.

To explore the windows of opportunities available in each farm type to minimize water and balance nitrogen use for different target farm profits, a trade-off analysis was done between income, water use and partial N-balance with only current farm practices. The model results showed that, The windows of opportunities available for farmers to balance between their economic objective and the environmental objectives of the society varied among the four farm types (Figure. 1). Farm Type 1 had more options to choose from in combining these objectives to reduce the water use and improve the N-balance for any given level of farm profit compared with the other farm types (Figure. 1). In Farm Type 1, with the given constraints on land use, the number of available crop choices and farm resources were high and the opportunities became wider. In Farm Type 2, though they had many crop choices (Table 4 in Chapter 5), the options were limited by the large differences in the profitability of the crops thus narrowed down the windows of opportunities. For instance, the most profitable banana in Farm Types 1 and 3 was less profitable in this farm type and used more water than rice. Kharif rice which required more canal and well water was replaced by less water consuming green gram at a water price of US$ 0.01 m^{-3} (see Table 6 in Chapter 5).

Farm Type 3 had better opportunities than Farm Type 2 though the crop choices were limited to Kharif and Pishanam rice, and banana. However, the opportunities were restricted by the limited resource endowments, i.e., maximum land area available is only 1 ha. In Farm Type 4, the windows of opportunities were restricted by low level of resource flow. The crops cultivated in this farm type used very little inputs such as water and nutrients and the outflows were also limited due to lower yields. However, the farm profit was increased manifold by selecting the optimal crop choices which used fewer resources and produced more income, such as pulses and vegetables.

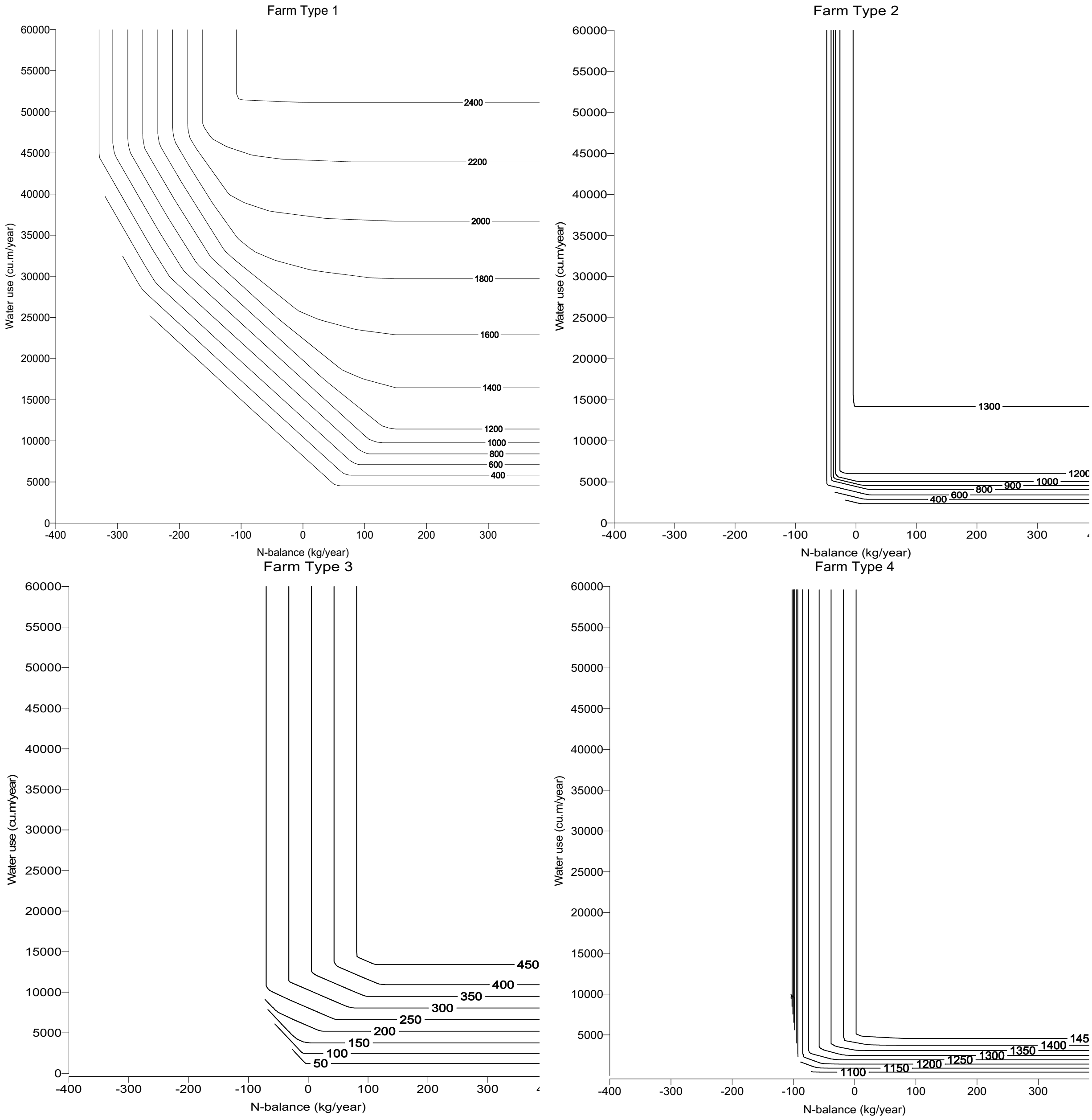

Figure. 1. Trade-off between water use and partial N-balance for different levels of targeted farm profit (US$ y^{-1}) with the current farm practices. The contour lines are isoprofit (see profit on each line) lines for different quantities of water use and corresponding partial N-balances. Where lines stop the model solutions become infeasible.

All the available windows of opportunities identified by the trade-off analysis would not be used by a farmer to maximize the farm income. For example, in Farm Type 1, for a target farm profit of US$ 1800 y^{-1}, the farmer could use 30,000 m^3 of water with +200 kg of partial N-balance or 45,000 m^3 of water with -200 kg of partial N-balance (Figure. 1). These two extremes of water use and N-balance may be due to the selection of very different land uses but farmers may want to satisfy many objectives

such as food self sufficiency, cash income, more free time rather than a single objective which may reduce the number of opportunities a farmer is willing to practice. The limitation in this trade-off analysis is that we calculated partial N-balances only for the selected land use. The model was not free to choose a fertilizer that contained more nutrients or was cheaper in the market since the fertilizer choices for a crop were fixed. We did not have the crop output data for different rates of nutrient inputs to allow us to do this.
We will extend these type of trade-off analysis further in the near future to many more scenarios by including the modified rice cultivation and different level of water pricing and water quotas.

8. Looking back

In this study, we conducted on-station experiments, on-farm adaptive research trials, rapid and detailed farm surveys, quantified resource allocation and resource use efficiencies in farmer's fields and used modeling approaches to analyse the options to enhance the water use efficiency of rice-based farms in Tamil Nadu, India. We identified the solutions for the water problems as well as new problems and then moved on to look for solutions for the new problems (Chapters 1 to 5). Adoption of modified rice cultivation by farmers will enhance the water productivity in rice by reducing the water use and increasing the yield. However, the practical difficulties with the novel cultivation practices need to be solved for large scale adoption. Classifying farms into farm types helped to understand the structure and functioning of the rice-based farms and to assist analysis on technology adoption by imposing policy measures. Impact of the latter should consider the differences in the resource endowments of farms. Differences in resource endowments of farmers led to differences in resource use efficiencies and sufficient care should be taken of these differences while bridging the objectives of both farmers and the society at large. The model results showed that the combination of modified rice cultivation and water pricing policies can enhance the water use efficiency of the region while water quota can protect livelihoods of farmers that are too strongly disadvantaged. However, policy measures such as development of irrigation infrastructure, training and education and co-operative management of water resources can also have an effect on improving resource use efficiencies and farmers' livelihoods. Farm explorative studies are useful in identifying optimal land use choices to achieve specific objectives of a farm, and to assess impact of policy interventions *ex ante* on farms varying in resource endowments and characteristics.

9. Looking ahead

Through this study, what we achieved is an entry point to solve the water scarcity problems of the state. The research has to be continued to find options to enhance the resource use efficiencies and farmers' livelihoods in the state. Experiments are need to be conducted on water-saving irrigation in rice by considering all aspects of water inflows and outflows at a larger field scale. Farm surveys need to be conducted on farmers' opinions on changing cropping pattern, willingness to pay for electricity and water use, redistributing water delivery systems in the state to facilitate the policy makers to impose acceptable policy instruments to the farmers. The water potentially available in the state and the potential crop production and productivity that can be achieved by using the water resources efficiently need to be quantified, and regional scale modelling approaches can be used for this purpose. The possibilities of redistributing the water resources through linking rivers need to be designed and the future scenarios of water resource development and use need to be explored. In this study, the adoption of water saving irrigation by the farmers were assessed in a relatively water-abundant river basin of the state. The analysis could be extended to the water-scarce areas of the state where rice is cultivated only for home consumption. Government policy measures such as training and education on modified rice cultivation practices, development of irrigation infrastructure and organised cooperative management of commonly available water resources and their impact on enhancing resource use efficiencies and farmers' livelihoods need to be assessed. Another aspect for policy consideration revolves around opportunities to stabilize food price fluctuations through processing and storage of perishable farm products and thus to provide price support instruments for all crops need to be developed.

Farmers livelihoods and saving water in rice are the two important issues addressed in this thesis. The thoughts of the famous Tamil poet Thiruvalluvar in 1st millennium BC, reflected on the livelihoods of the farmers and the importance of water. Farmers' then were considered to deserve respect as they fed the world and today they continue to do so, however, efforts are needed to position them at higher level of the society by improving their livelihood standards. Thiruvalluvar wrote, "Water is life that comes from rain; Sans rain our duties go in vain", this could be adapted to the current water-scarce situation as, "Saving water is life that comes through knowledge; Sans saving water our duties go in vain".

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Mathematical formulation of the model (Chapter 5)

The model formulation presented here is linear and can be solved using linear programming (LP). The objective functions are: 1) maximizing farm profit; 2) minimizing water use; 3) optimizing partial N balance towards zero.

The different Land Use Activities (LUA) are the decision variables in the model. These activities are defined as crop production on a hectare of land characterised by all the relevant inputs and outputs for each crop or crop category [index *cc*], land type [index *ac*] on a weekly basis [index *w*]. Inputs and outputs of all crops are quantified using data collected under current, conventional, management practices. For rice production systems, however, an alternative cultivation technique using modified practices is defined. This management system differs from the conventional in planting (square planting of younger seedlings), irrigation (not permanently flooded), weeding (mechanical) and nutrient management (additional organic manure to already used fertilizers). An index is used to distinguish between conventional and modified rice cultivation techniques [index *mp*]. All production activities are parameterized for yield, water, labour and partial nitrogen balance. The coefficients for modified rice cultivation are obtained by multiplying the coefficient of those of the conventional rice production activities with a factor obtained from experiments. The multiplication factor for all conventional activities is then one. A total of 15 alternative combinations in modified rice cultivation are thus defined. All possible crop production activities per farm type are further defined by the weekly presence of the crop in a year using the crop calendar. Table 1 summarizes all elements of the crop index, in which farm type they appear and on what land type (wetland (WL) and irrigated dryland (GL).

Further indices used are crop products [*cout*] (Main and by-product), four types of labour [index *lt*] (Family men and women, Hired men and women), five different water sources [index *ws*] (Well, Canal, System tank, Rainfed tank and Rainfall), 23 type of fertilizers [index *fc*] (Urea, DAP, MoP, Comp1, Comp2, Comp3, Fact, AmoChl, AmoSul, SSP, Micro, Horn, Vermi, Gypsum, Zn, Neemc, Gnutc, Biome, Biofert, FYM, Penn, Seed_treat, Gherkin_Mixer) and five machine types [index *m*] (Machine, Implement, Harvester, Electric motor, Diesel motor).

In the formulation, multiple summations over different indices are indicated by a single *sigma* (e.g. $\sum_{cc,ac,w,mp}$), equivalent to a series of *sigmas*, separately for each index ($\sum_{cc}\sum_{ac}\sum_{w}\sum_{mp}$).

All constraints and balances are calculated on a weekly basis except for profit and costs. The objective functions are modelled for a period of one year.

CONSTRAINTS

LAND

Available land per land type

$$\sum_{cc,mp} vX_{cc,w,mp} \leq LA_{ac}$$

Where:

vX: Land allocated to a crop[cc] per week [w] under certain management practice [mp] (ha)

LA_{ac}: Land available per land type [ac] in a farm (ha)

Food self sufficiency

A minimum quantity of rice to be produced from the two rice crops (Kharif and Pishanam rice) to meet the family food requirements:

$$\sum_{ac,w,mp} vX_{cc_r,ac,w,mp} \bullet CY_{cc_r,ac,cout,w} \geq Rice\_SS_{cout}$$

Where:

CY: Crop yield (kg ha^{-1})

Rice_SS: Minimum quantity of rice required for food self sufficiency to be defined by the model user (kg $farm^{-1}$)

$cout_{rg}$: Rice grain, a subset of [cout] (kg ha^{-1})

cc_r: Sub set of the index crops [cc] being the rice crops identified to grow in Kharif and Pishanan season

Maximum land for rice per land type

The maximum land area that can be allocated to rice cultivation per land type, which is a parameter that has to be defined by the model user:

$$\sum_{mp} vX_{cc_r,ac,w,mp} \leq Rice\_CA_{ac}$$

Where:

$Rice\_CA_{ac}$: Maximum land area under rice per land type [ac] (ha)

Maximum land for vegetables per land type

The maximum land area that can be allocated to vegetables per vegetable type, which is a parameter that has to be defined by the model user:

$$\sum_{mp} vX_{cc_v,ac,w,mp} \leq Vegetable\_CA_{ac}$$

Where:

$Vegetable\_CA_{ac}$: Maximum land area of all vegetable types grown per land type (ha)
cc_v: Sub set of the index crops [cc] containing the vegetable crops

Maximum land for banana per land type

The maximum land area that can be allocated to banana per land type, which is a parameter that has to be defined by the model user:

$$\sum_{mp} vX_{cc_b,ac,w,mp} \leq Banana\_CA_{ac}$$

Where:

$Banana\_CA_{ac}$: Maximum land area under banana per land type (ha)
cc_b: Sub set of the index crops [cc] being the Banana crop

Land constraint on rice nursery

Per ha of rice crop, 0.08 ha of nursery should be allocated to produce rice seedlings for planting:

$$vX_{cc_n,ac_n,w_n,mp} = 0.08 \bullet vX_{cc,ac,w,mp}$$

Where:

cc_n: Sub set of crop index [cc] containing the rice nursery activities
ac_n: Land type used for the cultivation of rice nursery
w_n : Rice nursery growing weeks corresponding to the main rice crop

LABOUR

Labour balance per week

$$TLN_w \leq TLA_w$$

Where:

TLN: Total labour needs per week [w] (labour days)
TLA: Total labour available per week [w] (labour days)

Labour available per week

The maximum days of labour available in a farm per week:

$$TLA_w = \sum_{lt} AL_{lt,w}$$

Where:

AL: Available labour per labour type [lt] (labour days)

Labour need per week

Labour needs per labour type for all cropping activities in a farm per week:

$$TLN_w = \sum_{cc,ac,mp} (vX_{cc,ac,w,mp} \bullet LN_{cc,ac,lt,w} \bullet L\_CF_{mp})$$

Where:

L_CF: Labour coefficient for conventional or modified management practice

WATER

Water balance per land type per week

$$TWN_{ac,w} = TWA_{ac,w}$$

Where:

TWN: Total water need for all selected cropping activities per week [w] per land type [ac] (m^3)
TWA: Total water available per week [w] per land type [ac] (m^3)

Water need per land type per week

The total water requirement for all cropping activities:

$$TWN_{ac,w} = \sum_{cc,mp} (vX_{cc,ac,w,mp} \bullet WN_{cc,ac,w} \bullet WU\_CF_{mp})$$

Where:

WN: Water need (m^3)
WU_CF: Water use coefficient per conventional or modified management practice [mp]

Water available per land type per week

Total water available from all the different water sources:

$$TWA_{ac,w} = \sum_{ws} WU\_WS_{ac,w,ws}$$

Where:

WU_WS: Water use per water source [ws] per land type [ac] per week [w] (m^3)

NITROGEN

Total fertilizer N need per crop

$$TFN_{cc} = \sum_{ac,w,mp,fc} (vX_{cc,ac,w,mp} \bullet NC_{fc} \bullet FN_{cc,ac,fc,w})$$

Where:

TFN: Total fertilizer need per crop (kg ha^{-1})
NC: N fraction in fertilizer
FN: Fertilizer need per crop (kg ha^{-1})

Partial N balance per crop

$$CNB_{cc} = N\_IF_{cc} - N\_OF_{cc}$$

Where:

CNB: Crop level partial nitrogen balance (kg ha^{-1})
N_IF: N inflow per crop (kg ha^{-1})
N_OF: N outflow per crop (kg ha^{-1})

N inflow per crop

Quantity of N input per crop:

$$N\_IF_{cc} = \sum_{ac,w,mp,mc} (vX_{cc,ac,w,mp} \bullet S_{cc,w} \bullet SN_{cc}) + TFN_{cc}$$

Where:

S: Seed input (kg ha^{-1})
SN: N fraction in the seed

N outflow per crop

Quantity of N outflow per crop:

$$N\_OF_{cc} = \sum_{ac,w,mp,cout} (vX_{cc,ac,w,mp} \bullet CY_{cc,ac,cout,w} \bullet CY\_N_{cc,ac,cout})$$

Where:

N_OF: N outflow per crop (kg ha^{-1})
CY: Crop yield (kg ha^{-1})
CY_N: N fraction in the crop outputs

COSTS

Total cost of cultivation per year

The sum of all the costs of all cropping activities:

$$TC = \sum_{lt} TLC_{lt} + \sum_{cc} TSC_{cc} + \sum_{fc} TFC_{fc} + TPC + TWC + \sum_{m} TMC_{m} + \sum_{cc} TTC_{cc}$$

Where:

TC: Total cost of cultivation all crops (US$)
TLC: Total labour cost for all labour types [lt] (US$)
TSC: Total seed cost for all crops [cc] (US$)
TFC: Total fertilizer cost for all fertilizer types [fc] (US$)
TPC: Total pesticide cost (US$)
TWC: Total water cost for all water sources [ws] (US$)
TMC: Total machinery use cost for all machine types [m] (US$)
TTC: Total crop transport cost for all crops [cc] (US$)

Total labour cost per labour type per year

$$TLC_{lt} = \sum_{cc,ac,w,mp} (vX_{cc,ac,w,mp} \bullet LC_{cc,ac,lt,w} \bullet LN_{cc,ac,lt,w})$$

Where:

LC: Cost of labour per hectare crop activity per land type per labour type (US$ per labour day per hectare)
LN: Labour need per crop activity per labour type (labour day)

Total seed cost per crop per year

$$TSC_{cc} = \sum_{ac,w,mp} (vX_{cc,ac,w,mp} \bullet SC_{cc} \bullet SI_{cc,ac,w})$$

Where:

SC: Unit price of seed per crop (US$ kg^{-1})
SI: Seed input per crop (kg ha^{-1})

Total fertilizer cost per fertilizer type

$$TFC_{fc} = \sum_{cc,ac,w,mp} (vX_{cc,ac,w,mp} \bullet FC_{fc} \bullet FN_{cc,ac,fc,w})$$

Where:

FC: Unit cost of fertilizer (US\$ kg^{-1})
FN: Fertilizer need per crop (kg ha^{-1})

Total pesticide cost

$$TPC = \sum_{cc,ac,w,mp} (vX_{cc,ac,w,mp} \bullet PC_{cc,ac,w})$$

Where:

PC: Unit price of pesticides including application charges per crop (US\$ ha^{-1})

Total water cost

Cost of water used in a farm from all the water sources excluding rainfall in a year:

$$TWC = Pos \bullet WP$$

Where:

Pos: Quantity of water used above the quota limit (m^3)
WP: Unit price of water (US\$ m^{-3})

Water cost quota

No pricing on the quantity of water given to a farm as water quota, which is a parameter that has to be defined by the model user. If the farmer uses more water than the water quota, the excess water will be priced normally:

$$(\sum_{ac,w,ws} WU\_WS_{ac,w,ws} - WQ_{ws}) + Neg - Pos = 0$$

Where:

WQ: Quantity of water given as quota to a farm per water source [ws] (m^3 y^{-1})
Neg: Amount of water used which is less than the water quota
Pos: Amount of water to pay for

Water use per water source per land type

$$WU\_WS_{ac,w,ws} \leq WA\_WS_{ac,ws_{nr},w} + \sum_{cc,mp} (WA\_WS_{ac,ws_r,w} \bullet vX_{cc,ac,w,mp})$$

Where:

WU_WS: Water use per water source[ws] (m^3)
WA_WS: Water available per water source [ws] (m^3)

ws_{nr}: Sub set of the index water source [ws] (Well, Canal, System tank, Rainfed tank)
ws_r: Sub set of the index water source [ws] (Rainfall)

Water available per water source per land type

$$WA\_WS_{ac,w,ws} = WA_{ac,ws_{nr},w} + \sum_{cc,mp}(WA_{ac,ws_r,w} \bullet vX_{cc,ac,w,mp})$$

Where:

WA: Water available from different water sources per land type defined by the model user (m^3)

Total machinery use cost per machine type

$$TMC_m = \sum_{cc,ac,w,mp}(vX_{cc,ac,w,mp} \bullet MC_m \bullet MU_{cc,ac,m,w}) + MMC$$

Where:

MC: Machinery use cost per machine type [m] (US\$ hr^{-1})
MU: Machinery use per machine type [m] (hr ha^{-1})
MMC: Machinery maintenance cost for all machines, defined by the model user(US\$)

Total crop transport cost per crop

$$TTC_{cc} = \sum_{ac,w,mp}(vX_{cc,ac,w,mp} \bullet CTC_{cc,ac,w})$$

Where:

CTC: Crop transport cost (US\$ ha^{-1})

PROFIT

Gross profit per year

$$GP = \sum_{cc,ac,w,mp,cout}(vX_{cc,ac,w,mp} \bullet CY_{cc,ac,cout,w} \bullet Y\_CF \bullet CP_{cc,ac,cout,w})$$

Where:

GP: Gross profit of the farm (US\$)
CY: Crop products [cout] of all crops (kg ha^{-1})
Y_CF: Multiplication factor for conventional or modified management practices [mp]
CP: Crop product [cout] price (US\$ kg^{-1})

OBJECTIVE FUNCTIONS

Maximizing farm profit per year

$$MAXPROFIT = GP - TC$$

Where:

MAXPROFIT: Maximum profit (US$)
GP: Gross profit (US$)
TC: Total cost of cultivation (US$)

Minimizing water use per year

$$MINWU = \sum_{ac,w,ws_{nr}} WU\_WS_{ac,w,ws}$$

Where:

MINWU: The minimum quantity of water used (m^3)

Optimizing partial N-balance towards zero

$$PNB = \sum_{cc} CNB_{cc}$$

Where:

PNB: N balance (kg)

Table 1. Overview of all possible crops per crop category, land type and farm type.

Crop category	Crop codes (cc)	Area code (ac)	Farm Type 1	Farm Type 2	Farm Type 3	Farm Type 4
Rice	Kharif_rice_nursery	WL	✓	✓	✓	
	Kharif_rice	WL	✓	✓	✓	
	Pishanam_rice_nursery	WL	✓	✓	✓	✓
	Pishanam_rice	WL	✓	✓	✓	✓
	Pishanam_rice	GL	✓			
	Kharif_rice_nursery	GL	✓			
	Kharif_rice	GL	✓			
Banana	Banana	WL	✓	✓	✓	
	Banana	GL	✓			
Vegetables	Brinjal_Clusterbean*	GL	✓			
	Ladiesfinger_1	GL	✓			
	Ladiesfinger_2	GL	✓			
	Tomato	GL	✓			✓
	Tuber	GL	✓			✓
	Gherkin	GL				✓
	Onion	GL				✓
Pulses	Blackgram_1	WL		✓		
	Blackgram_2	GL				✓
	Blackgram_3	GL				✓
	Greengram_1	WL		✓		
	Greengram_2	GL				✓
	Greengram_3	GL				✓
	Relay_pulse_1	WL		✓		
	Relay_pulse_2	WL		✓		
	Cowpea	GL				✓
Millets	Sorghum	GL				✓
	Fingermillet	GL				✓
	Pearlmillet	GL				✓
Oilseed	Sesame	GL				✓
Mixed crops	Blackgram_Sesame*	GL				✓
	Sorghum_Sesame*	GL				✓
	Cotton_Blackgram*	GL				✓

Crop codes with numbers are grown in different periods of the year; *Mixed crops; WL = Wetland; GL = Irrigated dryland or Garden land; ✓ = crop present on the farm.

Summary

Saving water?

Analysis of options for rice-based farms in Tamil Nadu, India

Water is an increasingly scarce resource and it should be used more efficiently by producing more crop per drop. Rice is the predominant crop in the state of Tamil Nadu, India and its cultivation consumes 70% of the water available for agriculture. Water productivity in rice was low, although, solely reducing water use in rice resulted in proportional reduction in yield. In nearly in 92% of the early experiments, water-saving irrigation treatments resulted in 0% to 70% yield loss compared with flooded treatments. Yield reduction with water-saving irrigation could not be achieved by the rice farmers of the state since 90% of all farmers cultivate less than 2 ha and being resource poor can hardly meet self-sufficiency. Therefore, a rice cultivation method was needed which can reduce water use without reducing, and even increasing yield. A new package of practices for rice cultivation was developed and called “modified rice cultivation” by changing the conventional planting, weeding and irrigation methods and adding green manure to the fertilizer regime. Modifications were: 1) instead of 24 – 35 days old seedlings from lowland nursery beds (P_1), 14 – 15 days old seedlings from a modified nursery were planted with wider spacing in a square pattern (P_2); 2) the conventional practice of irrigation to 5 cm water depth one day after disappearance (I_1) was replaced by a thin water layer of 2 cm by irrigating when small cracks appeared on the soil surface up to flowering, generally within 2 – 3 days after disappearance of the water layer (I_2). After flowering, fields were irrigated immediately after disappearance of the standing water; 3) manual hand weeding twice at around 20 and 40 days after transplanting (W_1) was replaced by mechanical weeding every 10 days up to 40 – 45 days after planting, starting at 10 days after transplanting (W_2); and 4) recommended mineral fertilizer (N_1) was supplemented with 6.25 t ha^{-1} green manure (N_2).

Experiments were conducted under on-station and on-farm conditions to compare rice production using single components of the new package and any combination of these with the conventional set of methods in rice cultivation. The results of on-station experiments showed that a combination of modified planting, water-saving irrigation, mechanical weeding and green manure application ($P_2I_2W_2N_2$) gave yields of 6.6 – 7.1 t ha^{-1}. These yields were higher than using conventional practices ($P_1I_1W_1N_1$) where yields between 6 – 6.2 t ha^{-1} were obtained. In the first experiment water-saving irrigation was followed up to flowering and after that conventional irrigation was followed in any combination of modified methods. This resulted in 41% water saving and no reduction in grain yield in the treatment with only water saving irrigation. In a second experiment, the water-saving irrigation was continued up to maturity which

resulted in 50% water-saving, but yields were then reduced by 0.3 t ha^{-1}. These results prompted to use water-saving irrigation only up to flowering in the subsequent on-farm experiments.

On-farm experiments were conducted at 200 locations, 100 each in Thamirabarani and Cauvery river basins of Tamil Nadu. These on-farm experiments were carried out by farmers under the supervision of research staff of Tamil Nadu Agricultural University. An overall yield advantage of 1.5 and 1.4 t ha^{-1} for the modified rice cultivation compared with conventional rice cultivation in the Thamirabarani and Cauvery river basin, respectively, was observed in these on-farm experiments.

Two farm surveys were conducted to understand the adoption and disadoption of the modified rice cultivation by the farmers. The survey results highlighted the pros and cons of the modified rice cultivation. The farmers were positive on the yield advantages using modified rice cultivation. However, there was limited adoption of modified rice cultivation due to the increased labour demand for modified planting, unwillingness of agricultural labourers to change practices, difficulties with modified nursery preparation and the need to replace cheap women's labour for hand weeding with more costly men's labour for mechanical weeding. Farmers had enough water in the rice growing seasons at free cost which gave no incentive to adopt water-saving irrigation. Moreover, practical difficulties in adopting water-saving irrigation such as poor irrigation infrastructure and the resulting unwanted flooding reduced the chances of adopting water-saving irrigation.

Potential for adoption of novel cultivation practices depends on the structure and functioning of the farm. As each farm household is unique, and we cannot explore the future options for each individual farm, categorisation in meaningful farm types became important. Four rice-based farm types were identified in Thamirabarani river basin based on biophysical and socio-economic characteristics of the farms using principal component and cluster analysis. The four farm types were different in farm size, farm family characteristics, labour use, possession of livestock, level of farm mechanization and available irrigation sources. The reliance on farming for family food security varied greatly among these farm types. The role of livestock in income generation was low in all four farm types and livestock keeping only contributed less than 5% to the total income. Income earned through off-farm activities was above 50% in all four farm types. A qualitative assessment of adoption possibilities of modified rice cultivation showed that opportunities existed to adopt one or more components of the modified rice cultivation in all four farm types. However, opportunities to adopt water-saving irrigation was found to be the least promising. Effective government policies in different policy domains such as rules and regulations, pricing, institutional building and infrastructure development, training and education to the farmers are needed to improve the adoption of modified rice cultivation, including water-saving irrigation.

Farmers tend to maximize economic output of farming activities which may not coincide with the optimal use of resources from an ecological perspective. However, improving resource use efficiencies at the regional scale is important for society at large. Efficiency can be enhanced by well-chosen combinations of resource efficient technologies at the farm level and policy interventions at the regional level. Policy measures will influence farmers' livelihoods differently because of differences in their resource endowments and characteristics. An identical set of policy interventions cannot be applicable in all farm types since current resource use efficiencies and adaptability to changes in policies differed substantially. Hence, we quantified current use efficiency of water, labour, nutrient and capital in all four farm types both at crop and farm level and qualitatively assessed the impact of different policy measures on farmers' livelihoods.

Resource use efficiencies of water, labour, capital and nutrients differed between the four farm types. Rice was the most important crop and its resource use efficiencies determined the farm level efficiencies in all four farm types, followed by banana in the first three farm types. Variation in resource use efficiencies across farm types showed the possibilities for enhancing the use of scarce resources through changes in cultivation practices and policy interventions. Water productivity was poor in Farm Types 1, 2 and 3 compared with Farm Type 4 due to the open access to the commonly available canal water for the farms of the first types. Labour productivity was highest in Farm Type 2 due to higher family labour use and least in Farm Type 3 due to the small operational holding. Farm Types 1 and 2 were most profitable and Farm Types 3 and 4 were least profitable which was directly related to the resource endowments. Farm Type 3 was least efficient in using all the resources considered, emphasizing the negative effect of low resource endowments. Sufficient care should be taken while bridging the objectives of both farm and regional level, i.e. improving the use efficiency of the resources without jeopardizing the livelihoods of the farming community.

The possible effects of the different policy instruments on improving the resources use efficiencies and the farmers' livelihoods in each farm type needed to be analysed quantitatively. Therefore, a static farm-level multi-objective linear programming model (MGLP) was developed to explore the impact of water pricing policies on adoption of modified rice cultivation and water-saving in rice and on farmers' income. The model analysis gave insight into the impact government policy instruments such as water pricing and water quota have on achieving both the objectives of farmers and society at large. Model results indicated that in all four farm types, opportunities existed to increase farm profit even without the introduction of modified rice cultivation by selecting land use options more optimal than the current ones. The effect on income differed between farm types as a result of differences in resource endowments and characteristics. If modified rice cultivation is offered as activities to the model as well, farm profit increased further in all four farm types, but the level of impact depended on percentage of area under rice cultivation. However, in these optimization runs, the value of the objective of farmers, (i.e. maximizing the farm profit) can be improved but the objectives of the society at large, (i.e. increasing the use efficiencies of the commonly available water resources) can only be achieved by imposing water pricing policies by the government. According to the model, this will adversely affect income of the less endowed farmers. This unwanted effect of water-pricing can be overcome by introducing water quota fine tuned to the need of individual farm groups. Providing targeted water quota will help the low resource endowed farmers to overcome the effect of water pricing policies.

Water pricing policy measures put pressure on the farmers to adopt water-saving irrigation. They will be unwelcome messages for the farmers and it may lead to socio-political unrest in the region. Policy measures such as training and education on modified rice cultivation practices, development of irrigation infrastructure and organised co-operative management of commonly available water resources are worthwhile to consider in future research since they may contribute to the adoption of water-saving irrigation in rice without jeopardizing farmers' income.

Water besparen?

Een analyse van opties voor rijst producerende bedrijven in Tamil Nadu, India.

Water voor irrigatie in de landbouw wordt steeds schaarser en zal daarom efficiënter moeten worden gebruikt door meer te produceren per druppel geïrrigeerd water. In Tamil Nadu, een staat in India, is rijst het hoofdgewas dat bij de teelt 70% van het beschikbare irrigatiewater gebruikt. In eerdere experimenten die beoogden de efficiëntie van watergebruik in de rijstteelt te verhogen, leidde een beperking in watergebruik tot een proportioneel verlies in opbrengst. In bijna 92% van deze experimenten leidde besparing in irrigatie tot 70% verlies in opbrengst. Een dergelijk verlies kan niet worden opgebracht door de rijstboeren omdat 90% minder dan 2 hectare land bezit. Nu al hebben ze moeite om voldoende te produceren voor hun zelfvoorziening. Daarom is er een teelttechniek nodig waarbij minder water wordt gebruikt en de opbrengst behouden blijft of nog kan worden verhoogd. Een combinatie met nieuwe technieken in de rijstteelt is ontwikkeld, de zogenaamde gemodificeerde rijstteelt, waarbij plantverbanden, manier van wieden en irrigatiemethoden zijn veranderd en waarbij groenbemesting naast de gebruikelijke kunstmestgift wordt toegepast. De specifieke wijzigingen in deze teelt zijn als volgt:
1) In plaats van 24-35 dagen oude zaailingen, opgekweekt in zaaibedden in de laag gelegen stukken land (P_1), worden 14-15 dagen oude zaailingen gebruikt die zijn opgekweekt op alternatieve zaaibedden. Deze jonge zaailingen worden in een wijder en een rechthoekig plantverband geplant (P_2);
2) In plaats van irrigatie tot een waterlaag van 5 cm op de dag direct nadat er geen waterlaag meer op het land staat (I_1), wordt tussen overplanten en bloei een waterlaag van 2 cm op het land gebracht maar pas nadat er kleine droogtescheuren in het grondoppervlak verschijnen wat meestal gebeurt op 2-3 dagen na het verdwijnen van de waterlaag (I_2). Na de bloei wordt het veld wel direct na het verdwijnen van de waterlaag bevloeid.
3) Het gebruikelijke wieden met de hand dat in een seizoen tweemaal gebeurt namelijk 20 en 40 dagen nadat de zaailingen zijn overgeplant (W_1), wordt vervangen door het wieden met een wiedmachine om de 10 dagen, te beginnen 10 dagen nadat de zaailingen zijn overgeplant tot 40-45 dagen (W_2);
4) Naast de gebruikelijke kunstmest (N_1) wordt 6.25 t ha^{-1} aan groenbemesting gegeven (N_2).

Er zijn twee experimenten uitgevoerd op proefstations waarin de opbrengsten werden vergeleken tussen teelten waarbij één of iedere combinatie van de voorgestelde technieken en de traditionele technieken zijn toegepast. De opbrengsten van rijst geteeld met de combinatie van gewijzigde plantmethode, besparing van irrigatiewater, mechanisch wieden en groenbemesting ($P_2I_2W_2N_2$) waren 6.6-7.1 t ha^{-1}. Deze waren hoger dan van rijst dat op traditionele wijze was geteeld ($P_1I_1W_1N_1$), namelijk 6-6.2 t ha^{-1}. Alleen de waterbesparingsmethode (tot de bloei de besparende methode en daarna op traditionele wijze geïrrigeerd; $P_2I_2W_2N_2$) levert een besparing aan water op van 41% terwijl er geen afname was in de opbrengst. In het andere experiment werd de waterbesparing ook doorgevoerd na de bloei. Dit leverde 50% waterbesparing op, maar de opbrengst was dan 0.3 t ha^{-1} lager. Het lijkt dus beter om alleen waterbesparing toe te passen tot de bloei.

Op 200 bedrijven, 100 in elk stroomgebied van de Thamirabarani en de Cauvery rivier in Tamil Nadu, zijn experimenten met de gewijzigde teelttechnieken uitgevoerd door boeren onder begeleiding van onderzoekers van de Tamil Nadu Agricultural University. De meeropbrengst aan rijst geteeld met gebruik van de gewijzigde technieken in vergelijking tot de traditionele teelt was 1.5 en 1.4 t ha^{-1} in respectievelijk het stroomgebied van de Thamirabarani en de Cauvery rivier.

Er zijn twee enquêtes uitgevoerd om te achterhalen waarom boeren de gewijzigde teelttechnieken al dan niet zouden toepassen. De resultaten belichten de voor- en nadelen van deze gewijzigde teelttechnieken. Boeren waren positief over de meeropbrengsten. Toch wordt de vernieuwde teeltechniek slechts beperkt ingevoerd omdat de nieuwe wijze van planten meer arbeid vergt, er een zekere weerstand bestaat tegen verandering van teelttechnieken, de methode van alternatieve zaaibedden aanpassingsproblemen kent, en het gebruik van machines voor het wieden betekent dat goedkope vrouwelijke arbeidskracht moet worden vervangen door duurdere mannelijke arbeidskracht. Op dit moment hebben boeren in het groeiseizoen toegang tot irrigatie zonder kosten waardoor er weinig stimulans bestaat om tot het besparen van water over te gaan. Bovendien wordt waterbesparing niet gestimuleerd door de slechte infrastructuur voor irrigatie; ongecontroleerde bevloeiing van de velden is eigenlijk de enige manier om te irrigeren.

De mogelijke toepassing van de nieuwe teelttechnieken hangt af van de structuur en het functioneren van het bedrijf. Omdat ieder boerenhuishouden uniek is en we niet voor elk individueel bedrijf opties voor toepassing van de nieuwe teelttechnieken kunnen verkennen, is het belangrijk om een typologie van bedrijven te ontwikkelen. In het stroomgebied van de Thamirabarani rivier hebben we vier typen van rijst verbouwende boerenbedrijven geïdentificeerd. Deze typologie is gebaseerd op biofysische en sociaal-economische karaktereigenschappen van de bedrijven waarbij gebruik is gemaakt van twee analyse technieken, de eerste die hoofdcomponenten kan onderscheiden (Principal Component Analysis) en de tweede die vervolgens bedrijven kan plaatsen in groepen die op elkaar lijken (Cluster Analysis). De vier typen onderscheiden zich van elkaar door bedrijfsgrootte, familiestructuur, gebruik aan arbeid, bezit van vee, niveau van mechanisatie en toegang tot type irrigatie mogelijkheden. De afhankelijkheid van boeren voor voedselzelfvoorziening varieert beduidend tussen de bedrijfstypen. In alle vier bedrijfstypen is de rol van vee in het genereren van inkomen laag, tot minder dan 5% van het totale inkomen. Het inkomen verkregen door activiteiten buiten het boerenbedrijf was in alle bedrijfstypen meer dan 50%. Een kwalitatieve inschatting van de mogelijkheden om de nieuwe rijstteelttechnieken te adopteren geeft aan dat er mogelijkheden zijn voor adoptie in alle bedrijfstypen van één of meer componenten van deze teelttechnieken. Echter, de mogelijkheden voor waterbesparing lijken het minst belovend. Effectieve overheidsmaatregelen op verschillende terreinen zoals instellen van regelgeving, betalen voor water, opbouwen van instituties en ontwikkeling van infrastructuur, voorlichting en onderwijs aan boeren, zijn nodig om de adoptie te verbeteren van de nieuwe teelttechnieken wat moet leiden tot besparing in irrigatiewater.

Boeren hebben de neiging om het inkomen uit hun bedrijfsactiviteiten te maximaliseren wat niet altijd samengaat met het ecologisch optimaal gebruik van hun natuurlijke bronnen. Toch is het efficiënte en ecologisch verantwoorde gebruik op regionaal gebied belangrijk voor de samenleving als geheel. Die efficiëntie kan worden verbeterd door een weloverwogen keuze van combinaties van efficiënte technieken op bedrijfsniveau en overheidsmaatregelen op regionaal niveau. Die maatregelen zullen een verschillend effect hebben op de verschillende bedrijfstypen vanwege de verschillende eigenschappen, bezittingen en productiemiddelen. Eén pakket van overheidsmaatregelen kan niet even effectief zijn voor alle bedrijfstypen omdat efficiëntie in het gebruik van productiemiddelen en daardoor de mogelijkheden tot aanpassing aan veranderde overheidsmaatregelen beduidend zullen verschillen tussen die bedrijventypen. Daarom hebben we de huidige efficiëntie van gebruik aan water, arbeid, nutriënten en kapitaal op zowel gewas als bedrijfsniveau voor alle bedrijfstypen gekwantificeerd. Daarna hebben we kwalitatief bepaald wat het gevolg van verschillende overeheidsmaatregelen voor de boeren zou kunnen zijn.

De efficiëntie van water-, arbeids-, kapitaal- en nutriëntengebruik verschilde tussen de vier bedrijfstypen. Rijst was het belangrijkste gewas en de genoemde efficiëntie voor dit gewas bepaalt de efficiëntie op bedrijfsniveau in alle bedrijfstypen. Banaan is het tweede gewas van belang in drie bedrijfstypen. Variatie in gebruiksefficiëntie tussen de bedrijfstypen geeft aan dat er mogelijkheden zijn voor verbetering in gebruik van de schaarse middelen door verandering in teelt- en overheidsmaatregelen. De efficiëntie in watergebruik was laag in de bedrijfstypen 1, 2 en 3 in vergelijking tot bedrijfstype 4, voornamelijk doordat zij vrije toegang hebben zonder kosten tot gemeenschappelijk beschikbaar irrigatiewater uit kanalen. Arbeidsproductiviteit was in bedrijfstype 2 het hoogst, doordat veel gezinsarbeid werd gebruikt, en het laagste in bedrijfstype 3 doordat dit type erg klein was in areaal maar met veel gezinsarbeid.

De bedrijfstypen 1 en 2 maken de meeste winst. Dit is direct gerelateerd aan de natuurlijke hulpbronnen and bezittingen waarover bedrijven beschikken. Bedrijfstype 3 was het minst efficiënt in het gebruik van water, arbeid, nutriënten en kapitaal wat het negatieve effect van beperkte beschikbaarheid aan hulpbronnen en bezittingen op inkomen versterkt. Aan de verschillen tussen bedrijfstypen moet dus voldoende aandacht worden geschonken wanneer getracht wordt een brug te slaan tussen doelstellingen van zowel bedrijven als de samenleving. Het verbeteren van de efficiëntie van het gebruik van schaarse middelen zoals water moet zo worden uitgevoerd dat het de bestaansmogelijkheden van de boerengemeenschap schaadt.

De mogelijke effecten van de verschillende overheidsmaatregelen op het verbeteren van de efficiëntie van het gebruik van natuurlijke hulpbronnen en de bestaansmogelijkheden van de boeren van elk type bedrijf is kwantitatief geanalyseerd. Daarvoor is een bedrijfsmodel ontwikkeld dat gebruik maakt van lineaire programmering voor het optimaliseren van meerdere doelstellingen (IMGLP). Hiermee kan het effect van betaling voor water en invoering van waterquota worden verkend als middel om de adoptie van waterbesparende rijstteelttechnieken te stimuleren en het inkomen van de boeren te verbeteren. De modelanalyses brachten inzicht in de uitwerking van overheidsmaatregelen zoals het betalen voor water en het instellen van waterquota op het bereiken van de doelstellingen van zowel boeren als de gemeenschap. De modelresultaten gaven aan dat in alle vier bedrijfstypen opties aanwezig waren om de winst van de bedrijven te verhogen zelfs zonder dat de alternatieve rijstteelttechnieken worden ingevoerd. Dit was mogelijk door de verdeling van landgebruik meer economisch optimaal toe te kennen aan de geteelde gewassen, met verschillende effecten tussen bedrijfstypen. Als het model ook de alternatieve rijstteelttechnieken kan kiezen, dan neemt de winst verder toe in alle vier bedrijfstypen, maar het niveau van toename hangt af van het percentage van het landareaal dat voor rijstteelt wordt gebruikt. Hoewel volgens de modelberekeningen de waarde van de doelstelling van de boeren (maximaliseren van de winst) kan worden verbeterd, kan de doelstelling van de gemeenschap (verbeteren van gebruiksefficiëntie van het voor algemeen gebruik beschikbare, schaarse water) niet anders worden bereikt dan door de overheid opgelegde eis om voor water te betalen. Volgens de modelberekeningen gaat dit ten koste van het inkomen van minder bedeelde boeren. Deze ongewilde effecten kan worden tegengegaan als er waterquota, vrij van kosten, worden toegekend waarbij de hoeveelheid is afgestemd op de behoefte van het individuele bedrijfstype en de te geven hoeveelheid water gericht is op het compenseren van negatieve effecten van het betalen voor water.

Betalen voor water zet de boeren onder druk om waterbesparende teelttechnieken toe te passen. Deze boodschap is niet erg welkom bij boeren en kan leiden tot sociaal-politieke onrust in de regio. Om dat tegen te gaan is er flankerend beleid nodig voor training en onderwijs in alternatieve rijstteelttechnieken, ontwikkeling van de irrigatie infrastructuur en beheer in coöperatief verband van gemeenschappelijk beschikbaar water. Dit is de moeite waard om te worden onderzocht want het totaal van deze maatregelen kan bijdragen tot het besparen van irrigatiewater zonder dat het inkomen en de bestaanszekerheid van boeren op het spel wordt gezet.

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I conducted my research work in Agricultural College and Research Institute, Killikulam for almost two years. It was a happy moment again reminding me of my student life in the same campus during my bachelors degree studies. I thank the Dean, Dr. P. Vivekanandan and all staff members for their kind assistance during my stay and work. I am also grateful to all the students of this college for their friendship.

Farm surveys and field observations in the tropics at more than 40ºC called for endurance. It also required support and team work. The assistance provided by G. Shunmugasundarapandian, D. Ravisankar and R. Srinivasan, my young and energetic assistants (Junior Research Fellows) is immense. Hi Guys! You are really great and you did a great job for me, thank you. Special thanks goes to Edwin van der Maden, who did his master thesis within my PhD project and helped me to kick start the research work in Tamil Nadu. Dear Edwin, my sincere appreciations for your enriching input and suggestions for my research.

I like to thank the farmers of both Thamirabarani and Cauvery basin of Tamil Nadu, who participated in my research and gave me all the information needed. I thank them for being patience and bearing all our disturbances during the farm surveys. We both (me and the farmers) were busy at the same time as it should be because more activities by the farmers means that more data need to be collected, implying more questions to them. They allotted their precious time to answer all our questions again and again. I appreciate their hospitality, coffee in home and tender coconut in farm, gave us energy to ask them a lot of questions. This research is for them that's why I opted to dedicate this thesis to them.

Life in Wageningen without my Indian friends would have been a little difficult. I thank all my Indian friends Arijith, Arun, Anjal, Anitha, Ajay, Aparna, Abhishek, Anand, Animesh, Albin, Basav, Bijo, Byjesh, Bobby, Bhaishab, Dhanavel, Feana, Ganesan, Garima, Kishore, Karishma, Mimi, Manimohan, Marimuthu, Manikkam, Madhumohan, Murali, Nagesh, Ramakrishnaiah, Ranvir, Rama, Radhika, Sangita, Shibu, Shital, Sameer, Sandeep, Sharad, Srinivasu, Thangamani, Uttara, Urmila, Vani, Veda and many more (sorry, if I missed somebody) for sharing the joy of friendship, very nice Indian food and music whenever we met. Special thanks to Ganesan, Kishore, Feana and Nagesh for their personal care, love and affection and suggestions while taking some crucial decisions in life. Special thanks also to Vasanth, Kugan, Vicky and their family members for their friendship and timely help whenever required.

During my undergraduate studies, my Entomology professor Dr. Kalyanasundaram used to say "If you have a person/friend other than your blood relation ready to do anything for you then you are a successful person in this world". I am a successful person because I have a few friends like that. Whenever I feel so happy or very much stressed I call my friends Sobana, Sella, Mariappan and Raja who are always ready to share my concerns, happiness and feelings. I just like to say thanks to them, not only for their friendship for the last 13 years but also for since remaining my friends .

Marriages are fixed in heaven! While doing my PhD, I could not afford to think about my marriage as my top most priority was to first accomplish my PhD programme. Nonetheless, during the tail-end of my PhD, Sangeetha came to my life. There was a pause until the submission of my thesis and she again resurfaced to the limelight of my heart, strongly and surprisingly agreeing to be the one for the rest of my life. I am welcoming her to be together in all our endeavours in life.

Without the family support, this dream would have been unattainable. My beloved parents: Kalimuthu and Saroja; and my sisters: Nageswari, Selvi, Vasanthi and Komala and all other family members, always wished me success in all my endeavours. This not only gave me moral support and strength but a determination to climb each step in my life. I thank them all for their wishes and blessings.

All of the above, I thank the Almighty for giving me the strength to make my dreams come true all the time in my life journey.

Curriculum Vitae

Kalimuthu Senthilkumar was born on April 21st, 1977 in Pudukottai, Tamil Nadu, India. He completed his higher secondary school education in 1995 and started with his BSc degree courses in Agriculture in the same year at the Agricultural College and Research Institute, Killikulam, Tamil Nadu Agricultural University (TNAU). After obtaining the bachelors degree in 1999, he worked as a Project Coordinator for an NGO, training women farmers in post harvest technology for a period of one and half years. He enrolled for his MSc degree in Agronomy from 2000 to 2002 at the Agricultural College and Research Institute, Madurai, TNAU, but later he shifted to the main campus Coimbatore after having won a Junior Research Fellowship sponsored by Dutch Ministry of Agriculture, Nature Management and Fisheries. He conducted field research on water-saving rice cultivation technologies. Later the findings were disseminated to more than a million farmers in the state of Tamil Nadu through the Department of Agriculture. During his MSc, he received an award for the best academic performance in farming systems studies and visited Plant Research International (PRI), Wageningen, for two months. The work experience at PRI created an opportunity to start a PhD at Wageningen University. In October 2003, he started his PhD at the Plant Production Systems group and the C.T. de Wit Postgraduate School for Production Ecology and Resource Conservation, within the "Water-less rice" project operated by Plant Research International, The Netherlands.

List of Publications[†]

1. Journal articles

*Senthilkumar, K., Lubbers, M.T.M.H., de Ridder, N., Bindraban, P.S., Thiyagarajan, T.M., Giller, K.E. (in prep). Policies to support economic and environmental goals at farm and regional scales: Outcomes for rice farmers in Southern India depend on their resource endowments.

*Senthilkumar, K., Bindraban, P.S., de Ridder, N., Thiyagarajan, T.M., Giller, K.E., 2008. Impact of policies on farm households varying in resource endowments and use efficiencies: which policy instruments to select? Land Use Policy. Submitted.

*Senthilkumar, K., Bindraban, P.S., de Boer, W., de Ridder, N., Thiyagarajan, T.M., Giller, K.E., 2008. Characterising rice-based farming systems to identify opportunities for adoption of rice cultivation modified to save water in Tamil Nadu, India. Agricultural Water Management. Submitted.

*Senthilkumar, K., Bindraban, P.S., Thiyagarajan, T.M., de Ridder, N., Giller, K.E., 2008. Modified rice cultivation in Tamil Nadu, India: Yield gains and farmers' (lack of) acceptance. Agricultural Systems. 10.1016/j.agsy.2008.04.002.

Thiyagarajan, T.M., Senthilkumar, K., Bindraban, P.S., Hengsdijk, H., Ramasamy, S., Velu, V., Durgadevi, D., Govindarajan, K., Priyadarshini, R., Sudhalakshmi, C., Nisha, P.T., Gayathry, G., 2002. Crop management options for increasing water productivity in rice. Journal of Agricultural Resource Management 1(4): 169-181.

2. Proceedings papers and others

Senthilkumar, K., Lubbers, M., de Ridder, N., Bindraban, P.S., Giller, K.E., 2007. Exploring alternatives for sustainable rice-based farming systems in Tamil Nadu, India. In: Farming Systems Design 2007, Int. Symposium on Methodologies on Integrated Analysis of Farm Production Systems, M. Donatelli, J. Hatfield, A. Rizzoli Eds., Catania (Italy), 10-12 September 2007, book 1-Farm-regional scale design and improvement, p. 39-40.

Thiyagarajan, T.M., Senthilkumar, K., Priyadarshini, R., Ezhilrani, K., Jothimani, S., David, P.M.M., Sundarsingh, J., Muthusankaranarayanan, A., Hengsdijk, H., Bindraban, P.S., 2005. System of Rice Intensification for enhanced water and rice

[†] Full articles included in this thesis are indicated with (*).

productivity in Tamil Nadu, India. 4th IWMI-Tata Annual Partners' Meet, February 24-26, 2005, Institute of Rural Management, Anand, p. 112-113.

Thiyagarajan, T.M., Senthilkumar, K., Priyadarshini, R., Sundarsingh, J., Muthusankaranarayanan, A., Hengsdijk, H., Bindraban, P.S., 2005. Evaluation of water saving irrigation and weeder use on the growth and yield of rice. Transitions in Agriculture for Enhancing Water Productivity. Proceedings of an International Symposium held at Agricultural College and Research Institute, Killikulam, India, 23-25 September, 2003, p. 3-18.

Senthilkumar, K., Ramasamy, S., Thiyagarajan, T.M., 2005. Impact of mechanical weeding on weed incorporation and rhizosphere soil stirring in low land hybrid rice. Extended summaries, National Biennial Conference, ISWS, PAU, p. 110-113.

Senthilkumar, K., Ramasamy, S., Thiyagarajan, T.M., 2005. Effects of water management on hybrid rice productivity. National seminar on resource management for sustainable agriculture (RMSA), Department of Agronomy, Annamalai University, Abstracts, p. 31-32.

Sudhalakshmi. C., Velu, V., Thiyagarajan, T.M., Senthilkumar, K., 2004. Green manuring on nutrient availability and soil sustainability of rice hybrids. International conference on agricultural heritage of Asia. Souvenir and Abstracts, p. 131.

Thiyagarajan, T.M., Velu, V., Ramasamy, S., Durgadevi, D., Govindarajan, K., Priyadarshini, R., Sudhalakshmi, C., Senthilkumar, K., Nisha, P.T., Gayathry, G., Hengsdijk, H., Bindraban, P.S., 2002. Effect of SRI practices on hybrid rice performance in Tamil Nadu, India. Water-wise Rice Production. IRRI-Plant Research International, p. 119-127.

PE&RC PhD Education Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

The C.T. De Wit Graduate School PE&RC PRODUCTION ECOLOGY & RESOURCE CONSERVATION

Review of Literature (5.6 ECTS)
- Opportunities for saving water in rice-based farms to improve water productivity and enhance farmers' livelihoods in Tamil Nadu, India (2004)

Writing of Project Proposal (7.0 ECTS)
- Design of integrated rice-based systems for resource poor farmers in Tamil Nadu, India (2003)

Laboratory Training and Working Visits (1.4 ECTS)
- Bio-diesel project (Jatropha); ICRISAT, Hyderabad Acharya NG Ranga Agricultural University (ANGRAU), Hyderabad (2006)
- Project Land, Water and Ecosystems Management in the Krishna River Basin; Hyderabad Acharya NG Ranga Agricultural University (ANGRAU), Hyderabad (2006)

Post-Graduate Courses (2.8 ECTS)
- Advanced statistics; PE&RC (2007)
- Long-term dynamics of food and human development; PE&RC (2008)

Deficiency, Refresh, Brush-up Courses (5.6 ECTS)
- Quantitative Analysis of Cropping and Grassland Systems; PPS (2003)
- System analysis, Simulation and systems Management; PPS (2004)

Competence Strengthening / Skills Courses (1.4 ECTS)
- Scientific writing; CENTA (2004)

Discussion Groups / Local Seminars and Other Meetings (5.6 ECTS)
- Plant Soil relations; 2 years
- Sustainable land-use and resource management (with a focus on the tropics); 2 years

PE&RC Annual Meetings, Seminars and the PE&RC Weekend (1.5 ECTS)
- PE&RC day (2003)
- PE&RC programme day (2004)
- PE&RC introduction weekend (2004)

International Symposia, Workshops and Conferences (6 ECTS)
- International symposium on transition in rice cultivation for improving water productivity; Tamil Nadu Agricultural University, Tamil Nadu (2003)
- International symposium on methodologies and integrated analysis on farm productivity systems; Catania, Italy

Courses in which the PhD Candidate Has Worked as a Teacher
- Agronomy of field crops-I; Agricultural College, Killikulam, ,Tamil Nadu Agricultural University; 20 days

Supervision of MSc Student (s)
- Beyond Technological Solutions: farmers, water and the introduction of the System of Rice Intensification in the Thamirabarani river basin, Tamil Nadu, India. E.C.L.J. van der Maden, MSc. Thesis, Wageningen University, the Netherlands; 80 days