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Do investments in water management research pay? An analysis of water management research in India

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Abstract

Even though there has been increasing development of water management technologies over the years, the adoption rate by the farmers is comparatively small ranging from only 15–20%. Hence it is timely to look at the return to water management research investment to fine-tune investment in future research. A detailed study was done using the data from Tamil Nadu state, India. The successful technologies yielded a moderate return ranging from 11–20%. With higher adoption levels of the water management technologies, the rate of return will be higher. Strategies to boost technology transfer and upkeep should be given importance in water management programmes.

Keywords: Economic surplus; Research investment; Returns to water management research; Technology adoption

1. Background

Evaluating returns for research investment has been the main research agenda among agricultural economists, as the importance of assessing the impact of agricultural research is crucial. Returns for research investment determine its adoption and maximize the consumers' and producers' surplus. While many researchers attempted to evaluate returns for research investment in the agriculture and livestock sector (Evenson & Mckinsey, 1991), there is no clear evidence about returns for research

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investment in water management technologies. Water managers and policy makers are interested in the returns for research investment in water management, as a substantial budget has been spent on research programmes on water, even though the proportion of area covered under water management technologies is comparatively low (MoWR, 2006; Palanisami, 2010). The biggest question is whether water management research has yielded the expected benefits to society.

According to the Central Water Commission in India, with an improvement of 10% to existing water-use efficiency, the irrigated area can be increased by 14 Mha (MoWR, 2007). Thus, the future water needs of irrigation, which will continue to be the major source of India's future water demands, depend on water use technologies and their adoption. The research concept of 'more crop per drop' is better accepted in academic and policy circles in water resources research in India. While the water extraction and use technologies are available in the laboratory, there has been no effective transfer of technology across regions, seasons and crops, irrespective of water scarcity or abundance situations.

This paper analyses the returns for research investment in water management technologies, taking into account the research costs and the output from water management programmes in India, by selecting Tamil Nadu state as a case study, since about 67% of the gross cropped area in the state is covered by irrigation and several water management research schemes are already functioning in the state. The study has also focused on technologies that can be upscaled according to their profitability and adaptation strategies. The details of technologies taken up by the research institutes, the methodology used in the evaluation and the results of the analysis are discussed in the following sections.

2. Methodologies used for evaluation of research impact

Agricultural productivity can be increased by inducing public investment in research, extension, human capital and infrastructure (Rosegrant & Evenson, 1994). Such investments have helped to expand crop production and grain stocks in India (Kumar & Rosegrant, 1994). Pay-offs for agricultural research investment have been estimated by Evenson & Jha (1973), Evenson & McKinsey (1991), Rosegrant & Evenson (1994), Kumar & Rosegrant (1994) and Coelli & Rao (2005). But most of the studies on returns for investment in agricultural research have focused on improved crop varieties (Evenson & Jha, 1973; Evenson, 1989; Arndt *et al*., 1997), in spite of a significant share of agricultural research resources. Ananth *et al*. (2006) have estimated the impact of research investment on technology development by employing a total factor productivity approach. This measures the amount of increase in total output that is not accounted for, by the increase in total inputs. Rama Rao *et al*. (2010) have estimated the economic returns for investment made in soil and water conservation research on an *ex ante* basis. The authors have used an economic surplus (ES) model with a little spill-over effect on international trade, as cited by Alston *et al*. (1995) and Mills (1998). The results revealed that when adopted on a large scale, soil and water conservation measures generate significant ES, as reflected by high values of net present value (NPV), benefit cost ratio (BCR) and internal rate of return (IRR). In the present paper, the ES method has been used to assess the wide-scale impact of investments on water management technologies.

2.1. Economic surplus approach

The term 'surplus' is used in economics for consumer and producer-related quantities. The consumer surplus is the amount that consumers benefit by being able to purchase a product for a price that is less than they would be willing to pay. The producer surplus is the amount that producers benefit by selling at a market price mechanism that is higher than they would be willing to sell for. In the case of water management technologies, producers are mainly the farm households which produce the goods using the benefits of the technology interventions, and consumers are mainly the other stakeholders in the region, namely non-farm households representing labourers, people operating businesses and people employed in non-agricultural activities. The ES method is widely followed for evaluating the impact of a technology on the economic welfare of households (Nagy & Quddus, 1998; Maredia *et al.*, 2000; Moore *et al.*, 2000; Swinton, 2002; Wander *et al.*, 2004). The ES method's goal is to measure the aggregated social benefits of a research project. With this method it is possible to estimate the returns for investments by calculating a variation of the consumer and the producer surplus through a technological change originating from research. Afterwards, the ES method is utilized, together with the research costs, to calculate the NPV and BCR (Maredia *et al.*, 2000). The model can be applied to the small/large and open/closed economy within the target domain of the production environment.

2.1.1. Theoretical framework. The main focus of an impact assessment analysis is to compare a situation *without* research, against an alternative situation *with* research. The ES method provides a relatively simple, flexible approach for specifying the value of research, by comparing the situations with and without it. This method begins by recognizing that production levels depend on the use of a wide range of inputs. Each of these has a cost to the producer. The higher the price (or value) of the product, the more inputs it is worthwhile to use and the higher is the level of production. A higher product price will bring more inputs into each hectare and more hectares under the crop (Masters *et al.*, 1996).

The purpose of the supply and demand curves is simply to establish clear scenarios of what would happen with or without research; ES permits us to evaluate the difference between these two situations using a single measure. Any change in ES is a measure of the social benefits derived from research.

The influence of production costs on production levels can be given as a mathematical function known as a 'supply curve':

$$P_s = f(Q_s) \tag{1}$$

The supply curve slopes upward, showing that increases in the 'supply price', P_s, of a good are linked to increases in the 'quantity supplied', Q_s. In other words, the supply curve indicates that it is not possible to raise production levels without raising the price paid, unless something else changes to 'shift' the supply curve. Such a 'supply shift' could be anything that changes the costs of production, such as a change in the value of important inputs like labour or land, or a change in production methods like use of a new crop variety. It is appropriate to consider the curve to be straight line, in which case the inverse function will also take a linear form. Thus, the supply function can be expressed mathematically as:

$$Q = a_s + b_s P \tag{2}$$

where b_s is positive and represents the increase in the quantity supplied per unit increase in the supply price.

As with supply, the ES approach to demand begins by recognizing that quantities consumed depend on prices paid. The relationship is described by 'demand function' and, mathematically, the demand curve can be written as:

$$P_d = f(Q_d) \quad (3)$$

The demand curve slopes down, capturing the idea that increases in the 'demand price', P_d, are linked to decreases in the 'quantity demanded', Q_d. A simple mathematical function that has this property is the linear function with negative slope. Its inverse will also be linear. Thus the demand curve takes the following form:

$$Q = a_d + b_d P \quad (4)$$

where b_d is negative and represents the decrease in the quantity demanded per unit increase in the price.

To complete the ES approach, we note that the observed levels of quantities produced and demanded must reach some 'equilibrium'. This may be a very temporary equilibrium, which will change as soon as there is a shift in the supply and demand curves. But at each point in time, for some particular location or region, there is a single quantity (Q) that is both supplied (Q_s) and demanded (Q_d), as well as a single price (P) that is both paid to suppliers (P_s) and received by demanders (P_d).

We can estimate the social value of a given production and consumption level using the concept of the 'ES', defined as the area between the supply and demand curves (Masters *et al*., 1996).

Figure 1 illustrates the impact of a successful research effort on the supply curve, the equilibrium price and quantity, and the ES. The innovation shifts the supply curve down and to the right. This shift in supply moves the equilibrium to a lower level of price (P_1) and a higher level of quantity (Q_1). For producers, the impact of research is to reduce production costs; in terms of ES this is represented by an increase in area between the without research (S_0) and with research (S_1) supply

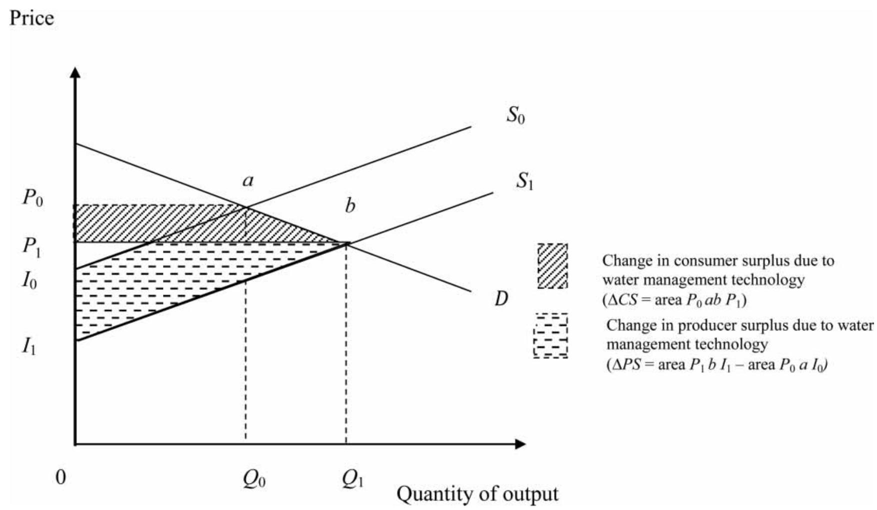

Fig. 1. Graphical representation of ES model.

curves and the area under the new price line P_1. But research also reduces the price received by producers, which reduces producer surplus by the area between the two price lines, above the without supply curve (S_0). For consumers, the effect of research is always a gain. They receive whatever was lost by producers due to lower prices, plus the ES on the increased quantity.

Consumers gain because they are able to consume a larger amount (Q_1) at a lower price (P_1). The area P_0abP_1 in Figure 1 represents this change in consumer surplus (ΔCS):

$$\Delta CS = \Delta AbP_1 - \Delta AaP_0 = \text{area of trapezium } P_0abP_1 = 0.5(P_0 - P_1)(Q_0 + Q_1) \quad (5)$$

The water management technologies affect agricultural producers in two ways: (i) lower marginal costs (according to the theory, the supply curve corresponds to the curve of marginal costs as to the minimum value of the curve of average variable costs), and (ii) lower market price (P_0 reduced to P_1). Thus, the change in producer surplus (ΔPS) is defined by the area P_1bI_1 – area P_0aI_0:

$$\Delta PS = \Delta P_1bI_1 - P_0aI_0 = 0.5[Q_1(P_1 - I_1) - Q_0(P_0 - I_0)] \quad (6)$$

The change in ES (ΔES) is the sum of these two changes and is given by:

$$\Delta ES = \Delta AbI_1 - \Delta AaI_0 = 0.5[Q_1(AI_1) - Q_0(AI_0)] \quad (7)$$

As the supply curve moves to the right, owing to positive impact of water management research in increasing productivity and reducing cost, the consumer gains benefit. Given that the demand function remains constant, the original market equilibrium $a(P_0, Q_0)$ is transferred by the effect of technological change to $b(P_1, Q_1)$. It is assumed that because of introduction of water management technologies, the supply curve will only shift right and there is no change in demand.

2.2. *Empirical estimation of change in economic surplus*

Using the linear forms of supply and demand functions (Equations (2) and (4)), explicit expressions for the three changes (Equations (5) to (7)) can be derived.

The initial equilibrium levels of price (P_0) and quantity (Q_0) are obtained by equating Equations (2) and (4). So we have:

$$P_0 = \frac{a_d - a_s}{b_s - b_d} \quad (8)$$

$$Q_0 = a_s + b_s P_0 \quad (9)$$

Further the demand and supply elasticities (absolute values), denoted respectively by η and ε, evaluated at the equilibrium point can be worked out as:

$$\eta = \frac{-b_d P_0}{Q_0} \quad (10)$$

$$\varepsilon = \frac{b_s P_0}{Q_0} \tag{11}$$

As discussed already, water management technologies will shift the supply curve downwards. The technology-induced change can be treated as an intercept change (a shift factor k) in the supply curve. That is, the intercept of the supply curve shifts downwards but there will not be any change in the slope. In other words there will be parallel shift. So the research-induced supply function can be written as:

$$Q^{(r)} = a_s + kb_s + b_s P \tag{12}$$

There is no shift or change in the demand function. So the new equilibrium price (P_1) and quantity (Q_1) can be derived by equating Equations (4) and (12). So:

$$P_1 = \frac{a_d - a_s - kb_s}{b_s - b_d} = \frac{a_d - a_s}{b_s - b_d} - \frac{kb_s}{b_s - b_d} = P_0 - \frac{KP_0 b_s}{b_s - b_d} \tag{13}$$

where $K = (k/P_0)$. Expressing the constants b_s and b_d in terms of elasticities given in Equations (10) and (11) and simplifying, we have:

$$P_1 = P_0 - KP_0\left(\frac{\varepsilon}{\varepsilon + \eta}\right) = P_0 - ZP_0 \tag{14}$$

where:

$$Z = \frac{K\varepsilon}{\varepsilon + \eta} \tag{15}$$

So:

$$P_0 - P_1 = ZP_0 \tag{16}$$

Now:

$$Q_1 = a_s + kb_s + b_s P_1 \tag{17}$$

Subtracting Equation (9) from Equation (17) and simplifying, it can be shown that:

$$\frac{Q_1 - Q_0}{Q_0} = \varepsilon(K - Z) = Z\eta \tag{18}$$

Now Equation (5) can be written as:

$$\Delta CS = (P_0 - P_1)\left(\frac{2Q_0 + Q_1 - Q_0}{2}\right) = (P_0 - P_1)(Q_0)\left(1 + 0.5\left(\frac{Q_1 - Q_0}{Q_0}\right)\right) \tag{19}$$

Finally, substituting Equations (16) and (18) in Equation (19) and simplifying we get:

$$\Delta CS = ZP_0Q_0(1 + 0.5Z\eta) \tag{20}$$

Next we shall derive an expression for change in ES using Equation (7). Now:

$$\Delta AbI_1 = 0.5Q_1(AI_0 + I_0I_1) \tag{21}$$

and:

$$\Delta AaI_0 = 0.5Q_0(AI_0) \tag{22}$$

So Equation (7) becomes:

$$\Delta ES = 0.5(AI_0)(Q_1 - Q_0) + 0.5I_0I_1Q_1 \tag{23}$$

It can be shown after a little bit of algebra that:

$$AI_0 = \frac{P_0K}{\eta Z} \tag{24}$$

and:

$$I_0I_1 = KP_0 \tag{25}$$

Substituting Equations (24) and (25) in Equation (23) and also using Equation (18) it can be shown that:

$$\Delta ES = 0.5[KP_0Q_0 + KP_0Q_0(1 + Z\eta)] = KP_0Q_0[1 + 0.5Z\eta] \tag{26}$$

Finally:

$$\Delta PS = \Delta ES - \Delta CS = (K - Z)P_0Q_0[1 + 0.5Z\eta] \tag{27}$$

The ΔCS, ΔPS and ΔES values are the same as derived by Alston *et al*. (1995).

The central piece of information for any research evaluation study using the ES method is the shift in the supply curve that has resulted from research (K-factor). Most commonly K is conceptualized as a vertical (downward) shift in the supply curve (Figure 2) where the water management technology

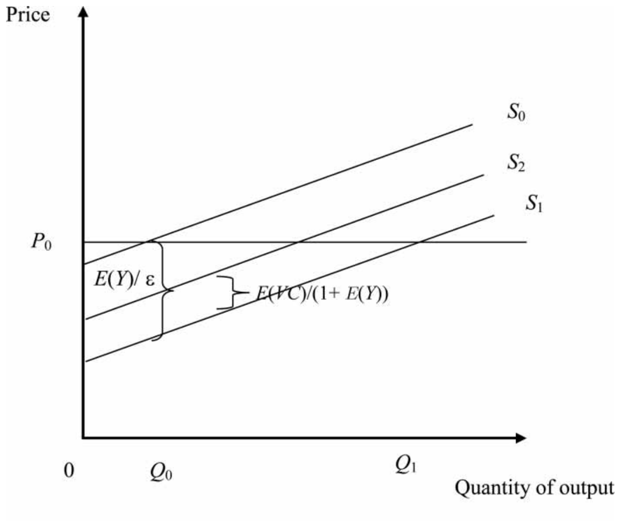

Fig. 2. Effect of research induced production increasing water management technology. *Source:* Jones *et al*. (2006).

shifts the supply function from S_0 to S_1. A greater output can be obtained for any level of cost of production. However, actually to achieve this increased level of production requires additional production costs (towards inputs and equipment etc.). Consequently there is a corresponding increase in unit costs associated with the technology and this is reflected in the shift in the supply function from S_1 to S_2. Thus the true shift from the technology is from S_0 to S_2 (Jones *et al*., 2006).

A number of options are available for estimating K, depending on the purpose of the analysis, data available and the method applied (Maredia *et al*., 2000). Some studies have estimated commodity–supply functions directly, with past expenditures on research included as an explanatory variable in an econometric model. Some studies estimated production functions and deduce the value of K from the estimated production function shifter (e.g. Akino & Hayami, 1975). These methods, however, require comprehensive time-series data on inputs and outputs. Hence most ex-post ES studies deduce the pattern of past supply shifts attributable to research based on the adoption rate of the technology and the per-unit cost reduction resulting from technological change (Maredia *et al*., 2000).

Thus K can be expressed as follows:

$$K = \alpha * \beta * \gamma * \mu \tag{28}$$

where K represents the vertical shift in supply caused by intervention of water management technologies and is expressed as a proportion of initial price. Here it is mainly assumed that the vertical shift in supply curve caused by water management interventions is only on the intercept and that there is no change in the slope of the supply curve. α is the net cost change and equals the difference between the reduction in marginal cost and the reduction in average cost of output. The reduction in marginal cost is the ratio of relative change in yield to price elasticity of supply (ε_s) which is represented as $(\Delta Y/Y)/\varepsilon_s$. where $\Delta Y/Y = E(Y)$. The reduction in average cost is the ratio of change in cost of inputs (including water cost) per hectare to (1 + change in yield) which is represented as $E(\mathrm{VC})/(1+E(Y))$. β is the probability of success in water management technologies in the farmer's field. γ represents the adoption rate of technologies and μ is the depreciation rate of technologies.

3. Sample and data

Presently, four water management schemes under the Tamil Nadu Agricultural University (TNAU) and Indian Council of Agricultural Research (ICAR) are functioning. These four water management research schemes, which are located in different agro-climatic zones, account for all the water management related research in the state. The major aspects of the water management schemes are given in Table 1.

In these four schemes demonstrations were conducted and various technologies were upscaled, mainly including the system of rice intensification (SRI), drip irrigation in both banana and sugarcane, drum seeding of rice, and water conservation and application for various crops. The details of these technological interventions are discussed below.

Table 1. Details of different water management schemes in Tamil Nadu state.

Scheme no.	Name of scheme and location	Year of start	Agro-climatic zone	Major crops	Major technologies tested	Total research staff[a] (no.)	Annual budget (in million Rs)
1	Water Technology Centre, Coimbatore	1984	Western	Rice, *jowar, ragi*, oilseeds, turmeric and cotton	SRI[b], Drip irrigation (sugarcane); drip irrigation (banana)	12	2.74
2	ICAR Water Management Scheme, Madurai	1991	Southern	Rice, *cholam, cumbu, ragi*, groundnut, cotton, banana and tobacco	SRI, Drip irrigation (sugarcane); drip irrigation (banana)	14	5.55
3	ICAR Water Management Scheme, Bhavanisagar	1969	Western	Rice, sugarcane, cotton, groundnut, sunflower, banana and ginger	SRI, Drip irrigation (sugarcane); drip irrigation (banana)	11	4.42
4	Soil and Water Management Research & Training Institute, Tanjore	1981	Cauvery Delta	Rice, sugarcane, cotton, groundnut, sunflower, banana and ginger	SRI, Drum seeding, water conservation and application	4	1.65

[a]Including supporting research staff such as research associates/research fellows. 1 US$ = Rs 46.
[b]System of rice intensification.

3.1. Technologies and water management practices included in the study

3.1.1. System of rice intensification (SRI). The SRI is an emerging rice cultivation practice as a potential alternative to traditional flooded rice cultivation (Batuvitage, 2002), particularly in canal systems. It is showing great promise in addressing the problems of small quantities of quality seeds, water scarcity and labour costs in the nursery. SRI has shown a positive difference in terms of plant height, number of tillers (both productive and unproductive), grains per panicle (filled and unfilled), and weight per 1,000 seeds. It has been observed that SRI plants are more vigorous, healthy and robust and are less damaged by pests and diseases. (Uphoff, 2002, 2004) has reported a doubling of rice yield through the SRI method from Asian and African countries based on the current average yield of 3.6 t/ha.

During the last few years, the SRI method of rice cultivation has received multidimensional support from different stakeholders in different rice production systems in India in general and Tamil Nadu state in particular. Efforts have been made to propagate this technological package to the farmers by providing input subsidies including a ‘cono weeder’, besides imparting training for their skill development in Tamil Nadu. The TNAU is taking the SRI to various regions of the state mainly to increase rice productivity and save irrigation water by minimizing water release at the canal level with a possible reduction in return flows. Palanisami *et al*. (2010) conducted a study in Tamil Nadu by selecting SRI and non-SRI farmers for three consecutive years (2007/08, 2008/09 and 2009/10) and *kuruvai* (June–September), *samba* (October–January) and *summer* (January–March) seasons. The study has observed large variations in the adoption of various key components of the SRI. Among the four key components (14-day-old seedling, single seedling, square planting and ‘cono-weeding’), only about 2% of the sample farmers in the *kuruvai* and s*amba* seasons and 4% in the *summer* season followed all the components. Three key components were followed by only about 4% of the farmers. The majority of farmers followed only one or two components.

3.1.2. Drip irrigation. Drip irrigation is one of the most efficient methods of irrigation (Keller & Blisner, 1990). Drip irrigation helps reduce over-exploitation of groundwater that partly occurs owing to inefficient use of water under the surface method of irrigation. The technology saves irrigation water, increases water-use efficiency, decreases tillage requirement, results in better quality products, reduces the cost of electricity, reduces the cost of well deepening and digging of new wells, reduces well failure rates and increases crop yields and fertilizer-use efficiency (Qureshi *et al*., 2001; Namara *et al*., 2005).

The introduction of drip irrigation has led to significant changes in landholdings, cropping area and irrigated area (Suresh Kumar, 2008). The average size of holdings among drip adopters is significantly large when compared to the non-adopters. The results show that drip irrigation has increased the net sown area, net irrigated area and thereby helped to achieve higher cropping and irrigation intensities. Several studies have been carried out to find out the impact of drip irrigation on different parameters of crop cultivation and water saving, including its economic viability in different crops (NCPA, 1990; INCID, 1994; Narayanamoorthy, 1997, 2003, 2004; Dhawan, 2002). The data compiled by the National Committee on the Use of Plastics in Agriculture (NCPA, 1990) have compared the yields and the water supplied for different crops under drip and conventional irrigation systems, and show a 23–288% increase in crop yields and a 36–68% saving in water supplied. Recent studies at farm level indicated that water saving due to drip irrigation ranged from 20–30% (ITP, 2011; Suresh Kumar & Palanisami, 2011). Shilp Verma (2004) has compiled the data from various research publications and has compared the water saving, yields and water-use efficiency (measured as kg/ha-mm) under drip and traditional methods of irrigation for ten crops. The results show a 13–70% increase in yields and a 25–79% saving in irrigation water. The author has also compiled results from different research stations in India for 16 crops, which have shown yield benefits of up to 77% and water saving of up to 80% on adoption of drip irrigation. Nonetheless a recent study by Palanisami *et al.* (2011) focused on the returns for micro irrigation adoption in different states of India.

3.1.3. Water conservation and application. Water conservation technologies include: (i) irrigation of fields directly through a separate field channel which saves water by 6.5–12% during the *kuruvai* season, (ii) use of a smaller plot size (1,000–2,000 m^2), effective land levelling and land shaping, and (iii) summer ploughing with a mould board plough which saves 20–30% of the water requirement for land preparation.

Water application technologies include: (i) irrigation to the depth of 2.5–5.0 cm after the disappearance of ponded water (in the Cauvery New Delta region), (ii) field submergence levels (daily topping) ranging from 2–10 cm, (iii) maintaining 2.5 cm water throughout the crop period and (iv) maintaining 2.5 cm up to the maximum tillering stage, draining water for 2 days and then maintaining 5 cm depth until 15 days prior to harvest, depending upon the soil condition.

3.1.4. Drum seeding of rice. Generally, rice seedlings are grown in a nursery for 30 days and then transplanted to the main field. This traditional method of transplantation requires additional time and water for rice cultivation. In the process of technology development to conserve water, short duration crops, direct seed sowing and drum seeding of rice are practised in many parts of the state. These practices also reduce production cost by reducing the number of tillages. The findings from such direct sowings in a wetland have shown that drum seeding of rice could reduce the seed rate (50%), labour-use (10%) and cultivation costs (15%) compared to the conventional method (Bala *et al.*, 2009).

3.2. Estimation of research cost

The data on cost of research on water management technologies from 1981 to 2008 were collected from the respective research stations of TNAU (Table 1). The research costs included the expenses incurred in the form of the salaries of scientists and other staff engaged in the respective water management schemes, the costs of field experimentation, and field trials including outreach activities for the major crops (rice, sugarcane and banana) where water management technologies are widely adopted.

The data on crop yield, water use, area covered, cost of cultivation, crop income, level of adoption of technology, rate of success and so on, were obtained from research station reports, publications, official records and through discussions with the extension officials and scientists from each region. Constraints on the adoption of these technologies were documented, based on the discussions with different stakeholders. Information on supply and demand elasticity, commodity prices and output quantities in the target domain was obtained from published and unpublished reports available at the TNAU. An interest rate of 8% representing the prevailing commercial bank lending rate was used to estimate the values of costs and returns. All the costs and prices were converted into 2004/05 constant prices using wholesale price indices.

3.3. Justification for cost and benefit inclusion

Research costs were proportionately allocated to different developed water management technologies considering the time and manpower spent on each of the water technologies in each research station. Finally, the research and extension costs associated with each technology at state level were arrived at by summing the respective costs from each research centre. Adequate care was taken to share the cost associated with each technology by discussion with the research scientists from the research stations. Some of the government programmes such as the National Agricultural Development Program (NADP) and Tamil Nadu Irrigated Agricultural Modernization and Water bodies Restoration and Management (IAMWARM) had some components of SRI and micro irrigation, and the costs associated with these extension activities were also included (see Appendix). Some of the technologies developed by the research centres such as irrigation scheduling, waste water treatment methods, physiological growth stages for stress management and so on, were not adopted in the farmers' fields because they were less applicable to field conditions. Hence these technologies, which accounted for less than 1% of the total research costs, were not included in the study.

4. Results and discussion

4.1. Adoption level of the water management technologies

The data on area covered, adoption level and average research cost of each technology in Tamil Nadu are summarized in Table 2. The area under water conservation and application methods in rice is comparatively higher than other technologies. In the case of drip irrigation under banana and sugarcane, both area and adoption levels are comparatively low.

4.2. Level of adoption of new technologies

The typical adoption pattern of the new technologies is shown in Figure 3(a)–(e). A look at these figures reveals that technology adoption initially increased, reached a peak and then decreased. This

Table 2. Area, research cost and spread of selected technologies.

Scheme no.	Technology	Current area (million ha)	Average research cost (million Rs/year) in constant prices[a]	Rate of adoption (%)	Year of start of research	Year of start of technology adoption
1	SRI[b]	0.289	1.55	20	2000	2003
2	Drum seeding of rice	0.193	1.29	15	1988	1994
3	Water conservation in rice	0.386	2.53	20	1981	1994
4	Water application in rice	0.394	2.68	20	1981	1994
5	Drip irrigation (sugarcane)	0.023	0.79	14	1995	2000
6	Drip irrigation (banana)	0.017	0.78	16	1995	2000

Note: The year of start of research technology was obtained from the research stations. SRI area reflects the adoption of three to four components of SRI. The actual adoption period was taken from the agricultural department officials at district level. There was a considerable time gap in the adoption of some technologies such as water application methods for rice on a large scale.
[a]Prices and costs are adjusted for 2004/05 constant prices. 1 US$ = Rs 46.
[b]System of rice intensification.

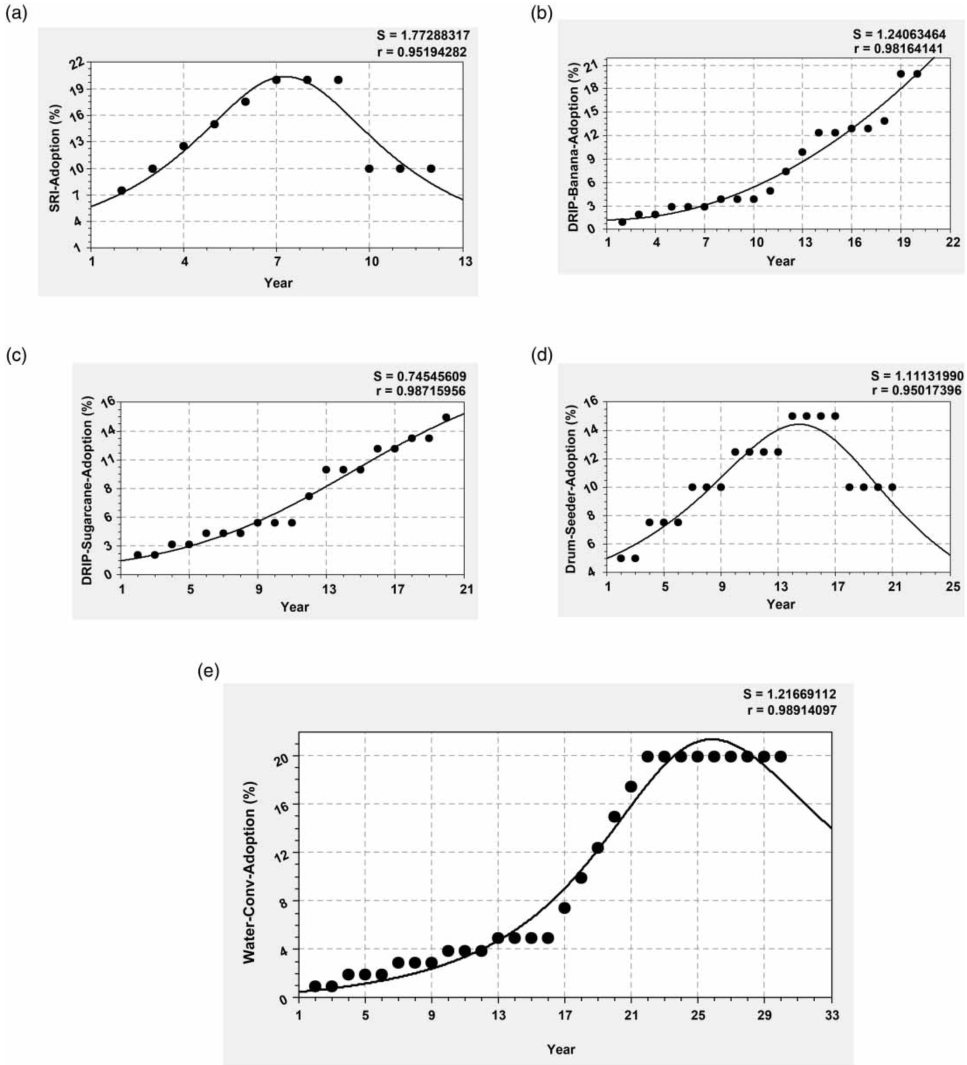

Fig. 3. (a) SRI[a] adoption, (b) drip irrigation adoption (banana), (c) drip irrigation adoption (sugarcane), (d) drum seeder adoption-rice, (e) water conservation technologies adoption. [a]System of rice intensification.

might be due to the effect of the technologies over time as well as due to the emergence of other technologies. The time series data on adoption levels of different technologies were analysed for their trends and the results are summarized below.

The trend in the adoption of the majority of the key components of SRI is slowly declining. After reaching a peak in the year 2009 with 20%, it has declined. In the case of the adoption of the drip irrigation for banana, the technology shows an increasing trend and it is projected that it will go up to 24% by 2014. Drip irrigation for sugarcane shows an increasing trend with a maximum adoption of around 15%. In the case of a drum-seeder for rice, the percentage of adoption of this technology has declined over the years with a maximum around 15% in 2007. Compared to drip irrigation technology, the adoption level of surface technologies for rice is high and this technology has stabilized around 20% but started declining afterwards.

It is interesting to note that the adoption pattern varies among the technologies and this is probably due to (i) the preference of farmers in adopting a technology available to them, and (ii) the constraints faced by them in its adoption.

Research costs will initially be high for a few years but once the benefits start flowing, the research costs related to that technology will be comparatively less and will mainly relate to maintaining certain adaptive research trials. The extension cost of the technologies is mainly based on the regional crop pattern, water supply, the farmers' knowledge when adopting the technology and the cost of the technology. For example, a typical drip irrigation technology will be slightly modified to give a specific amount of water according to the field conditions and crop pattern in a given soil type. The benefits of the technology will increase gradually and then fluctuate according to demand.

The adoption of a water management technology thus has been a function of the source of water and the rate of return of the technology. Where groundwater is used, adoption of technology is increasing (example, drip and water conservation), while in the case of surface water, adoption of technology initially increased and later decreased (example, SRI and drum seeding) mainly due to fluctuations in canal water releases and poor water control at farm level.

4.3. Returns for water management

The economic impact of various water management technologies was evaluated using the ES method. Increases in crop productivity ranged from 5–11% for rice and the probability of success varied from 20–25% among technologies. The price elasticity of both demand and supply for rice was −0.247 and 0.236, respectively. The consumer surplus and the producer surplus were calculated using Equations (20) and (27) and the ES was estimated using Equation (26). It is seen that among the different surface irrigation technologies introduced, SRI had the higher IRR (18%) followed by others (11–13%) (Table 3).

The micro irrigation intervention in both banana and sugarcane has doubled the cost of cultivation but has increased the yield by 35 and 21%, respectively (Table 4). The price elasticity of supply and demand for banana was 0.15 and −0.59, respectively. In the case of sugarcane, these values were 0.12 and

Table 3. Estimated returns from research investment in water management technologies for rice in Tamil Nadu[a].

Particulars	SRI	Drum seeding of rice	Water conservation	Water application
Yield in the year of start of adoption (t/ha)	3.0	2.8	2.8	2.8
Price of rice in the year of start of adoption (Rs/t)	5,300	3,560	3,560	3,560
Increase in productivity of crops (%)	10.8	5.0	9.0	10.0
Probability of success	0.20	0.20	0.25	0.25
Supply elasticity[b]	0.236	0.236	0.236	0.236
Demand elasticity[b]	−0.247	−0.247	−0.247	−0.247
BCR[c]	1.09	1.09	1.33	1.27
IRR[d] (%)	18.0	12	13	11

[a]Prices and costs are adjusted for 2004/05 constant prices.
[b]Constant supply and demand elasticity for rice is used under all the surface technologies considered in the study.
1 US$ = Rs 46.
[c]Benefit cost ratio.
[d]Internal rate of return.

Table 4. Estimated returns from research investments on drip irrigation for banana and sugarcane in Tamil Nadu[a].

Particulars	Drip: banana	Drip: sugarcane
Yield in the year of start of adoption (t/ha)	60	104
Price in the year of start of adoption (Rs/t)	5,200	888
Increase in productivity of crops (%)	35	21
Probability of success	0.3	0.3
Supply elasticity	0.15	0.12
Demand elasticity	−0.59	−0.34
BCR[b]	1.25	1.55
IRR[c] (%)	18.0	20

[a]Prices and costs are adjusted for the 2004/05 constant prices. 1 US$ = Rs 46.
[b]Benefit cost ratio.
[c]Internal rate of return.

−0.34, respectively. The economic benefits of research investment were significantly high in both banana (18%) and sugarcane (20%) indicating the financial viability of these technologies.

Investment in water management research had yielded higher returns than the commercial bank lending rate, as evidenced by the higher value of IRR compared to the bank lending rate of 8%. One could conclude that water management research had generated greater benefits for the economy.

What happens to returns for research investment if the adoption rate increases? This is an important policy question, which could inform policy makers about the impact of research as well as about measures to upscale the technologies. To visualize returns for research investment when the adoption rate increases by 10 and 20%, sensitivity analysis was performed and the results are discussed hereunder (Table 5).

It is evident from Table 5 that an increase in adoption rate of water management technologies would yield sufficient benefits for society. These benefits accrued mainly owing to increased adoption levels. Hence, research and extensions efforts should go hand in hand in order to achieve the increased benefits of research investment by society.

4.4. Constraints in adoption of a new technology

Even though water management technologies yield higher rates of return, farmers are not adopting the technologies as expected. For drip irrigation, there is a subsidy and the adoption rate depends on the

Table 5. Impact of research investment under a scenario of increased adoption rates of water management technologies.

Adoption scenario	Indicator	SRI[a]	Drum seeding of rice	Water conservation technologies	Water application technologies	Drip: banana	Drip: sugarcane
10% increase	BCR[b]	1.28	1.17	1.35	1.28	1.70	2.51
	IRR[c] (%)	25	13	13	12	21	25
20% increase	BCR	1.65	1.25	1.36	1.29	1.70	3.47
	IRR (%)	34	14	13	12	21	27

[a]System of rice intensification.
[b]Benefit cost ratio.
[c]Internal rate of return.

Table 6. Constraints faced by different stakeholders in technology adoption (number of responses).

Constraints	Researchers ($n = 11$)	Extension officials ($n = 23$)	Farmers ($n = 42$)
No action research in farmer's fields	10	2	4
Technology costly	5	7	22
Lack of expertise	2	19	34
Not suited to the local situation	2	21	35

Source: Survey data.

degree of economic scarcity of water. There is an element of informal extension effort through the drip irrigation dealer, while in SRI or surface irrigation-based technologies, there are no such efforts. Also, poor water control at farm level discourages farmers from adopting the SRI and drum seedling technologies, because in many canal systems water release is not uniform in quantity and time and this has affected SRI practices. Scarcity of labour for transplanting and weeding operations also constrains the adoption of the SRI in many locations. This further emphasizes the importance of human capital at the village level to facilitate the diffusion of water management technologies.

A quick survey was conducted regarding the slow rate of adoption of new technologies covering the researchers, extension officials and farmers. The major constraint reported by the researchers was lack of adequate budget for undertaking research trials in the farmers' fields (action research). Only a few schemes have provisions for on-farm research in a participatory mode. The extension officials reported that they were not being exposed to the latest water management technologies and also many technologies did not exactly match local needs. The farmers reported that the technologies were not user-friendly and always needed technical support. Also, some of them were too expensive to invest in and use (Table 6).

5. Conclusion and recommendations

The results of econometric analysis on the impact evaluation of the returns for water management research have yielded varying returns depending upon the nature of technology in terms of their adoption levels and the cost and benefits associated with them. Drip irrigation and SRI had higher returns compared to surface irrigation technologies. Also, some technologies are water and labour-saving while some are labour-augmenting. Most of the new technologies aim for water and labour-saving, which is also considered as a benefit. Hence, future water management technologies should aim to be both resource saving (water and labour) and yield increasing. A lack of skills in handling the technologies has also constrained their adoption by the farmers. Except for a few simple technologies such as drum seeding and alternate wetting and drying, most of the new technologies like drip and SRI need skilled manpower for effective use.

5.1. Recommendations

- Investment in water management technology research is justified even though the returns are not very attractive. The lower returns could be due to low levels of adoption of new technology. It is important that whenever a new technology is introduced, the capacity building of the field staff and/or farmers is ensured. Separate budget provision for this purpose should be inbuilt into the research programmes.

Further, these programmes should focus more on the technology dissemination aspects using already demonstrated successful technologies.

- Evaluation of existing water management technologies should be carried out periodically. The real water saving in SRI and drip irrigation needs to be evaluated in different physical environments and the technologies that have potential for upscaling should be widely disseminated as this will minimize the research cost of reinventing the same type of technologies in the near future.
- Technologies that are successful in one region can be transferred to other regions so that the rate of adoption could be increased. SRI and drip irrigation have more scope to upscale in suitable locations.
- A database of water management technologies, nature of spread and adoption patterns by different farm groups should be maintained by government departments for future technology evaluation.

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Appendix

Tamil Nadu government programmes – agriculture

The government programmes that include some components of the technology dissemination activities in Tamil Nadu state are listed below.

I. Assistance to the farmers for quality seed production: Seed multiplication scheme of rice, millets, pulses, oilseeds and cotton.
II. Assistance to farmers to increase crop productivity: rice and millets such as *cholam, cumbu* and *ragi*; and other minor millets such as *thinai, varagu, samai* and *kudiraivalli.*

   Cereals development programme – macro management mode schemes.
   Balanced and integrated use of fertilizers – macro management mode schemes.

III. Assistance to farmers to improve soil health. This includes: production and distribution of green manure seeds; distribution of micro nutrient mixture; distribution of bio-fertilizers; distribution of blue-green algae; vermicomposting of agricultural waste; composting of farm waste through pleurotus; reclamation of saline and alkaline soils; soil and water samples analysis.
IV. Assistance to farmers to take up plant protection measures: biological control of crop pests.
V. Assistance to farmers under extension and training.
VI. Tamil Nadu Irrigated Agricultural Modernization and Water bodies Restoration and Management (IAMWARM). SRI demonstrations with subsidy (Rs 6,000/ha).
VII. National Food Security Mission – Rice. Operating in Nagapattinam, Pudukottai, Ramnad, Sivaganga/Sivanaga and Tiruvarur districts. Input subsidy Rs 3,000/ac demo.
VIII. National Food Security Mission – Pulses. Operating in Coimbatore, Cuddalore, Nagapattinam, Namakkal, Tiruvallur, Tiruvarur, Thoothukudi, Tiruvannamalai, Vellore, Villupuram and Virudhunagar districts.
IX. Agriculture Technology Management Agency (ATMA).
X. National Agricultural Development Projects (RKVY). Precision farming subsidy. Drip fertigation at 50% subsidy (at Rs 40,000/ha) in 9 focused districts at 1,000/ha each and other 19 districts at 200 ha each.
XI. Dry land development and maximizing crop productivity.
XII. Establishment of Agri clinic-cum-mini soil testing laboratory.