SOCIAL COSTS AND BENEFIT OF MICRO IRRIGATION SYSTEM ADOPTION IN CANAL COMMANDS: A STUDY FROM IGNP COMMAND AREA OF BIKANER IN RAJASTHAN

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Abstract

It is generally perceived that adoption of micro irrigation (MI) system leads to increase in yield; real water saving; and expansion in area under irrigation, all resulting in social benefits. But, most of these perceptions are based on research on drip irrigated farms of orchards and cash crops. Again, they looked at saving in applied water rather than actual water consumption by the crop. Thus, the social benefits tend to get over-emphasized. Since the studies were done in agriculturally prosperous regions where labour is in short supply, the social costs associated with removal of labour from farms get ignored. Thus, governments and donors are motivated to subsidize MI systems. But, many research studies in the past on drip irrigation seem to suggest that these systems are viable even when the full costs of the system are compared against the private benefit. Hence, subsidies may not be desirable from an equity perspective as it is mostly large farmers having capital who go for micro irrigation systems.

The broad research question being addressed in the present study is whether subsidies are desirable for promoting micro irrigation systems in canal commands. The study was undertaken in IGNP (Indira Gandhi Nehar Project) command area where farmers have adopted sprinklers with the help of an intermediate storage system locally known as diggie. The objectives of the study are to: 1] analyze the farming systems changes associated with MI adoption; and, 2] evaluate the economic and social costs and benefits of sprinkler and diggie adoption in the region. The study shows that sprinkler with diggie is economically viable for the farmers even without subsidies. It further shows that the social benefits exceed the social costs.

The study had shown that under situations of induced water scarcity, incremental income return over pre-adoption scenario will not be the decisive criterion for farmers to go for MI systems. Instead, the criterion would be water productivity enhancement, which also ensures that the income returns are higher than what they would probably secure with flood-irrigated crops under conditions of reduced water availability. Since the social costs are less than the social benefits, the subsidies are justifiable as it makes the private benefits exceed the private costs. The study also validates the unique methodology used for economic cost benefit analysis of micro irrigation systems. On the social cost benefit front, we have only considered the positive externality associated with water saving. The other positive externality of sprinkler adoption is reduced risk in livestock keeping. However, we have not quantified this.

1. INTRODUCTION

Water scarcity problems are growing in many arid and semi-arid regions in India. Given the fact that agriculture consumes lion's share of total water diverted in these regions (GoI, 1999; Kumar, 2003), micro irrigation is advocated by the government of India (GoI) as a panacea for all water problems. The task force on micro irrigation constituted by government of India estimates the area that can be brought under micro irrigation systems at 97 mha. But, little attention has been paid to the constraints facing the farmers in adopting this system such as erratic power supply conditions; and lack of clear economic incentives for saving water and energy due to inefficient pricing of electricity and water. The existing cereal dominated cropping systems, and the small sizes of land holding of farmers are other physical constraints (Kumar et al., 2008). Particularly, in canal commands the delivery of water under gravity makes it difficult for farmers to adopt MI systems as they have to go for

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intermediate storage systems and pressurizing devices, which mean capital investments in addition to that required for the MI system making the economics poor. With the least recognition of these constraints, government has been using subsidy as an instrument for promoting adoption of MI.

That said, another important question which remains unanswered is whether subsidies are really justifiable. Subsidies are desirable when the social benefits exceed the social costs, whereas private benefits do not exceed the investment farmers have to make. Water saving and yield enhancement are generally perceived as positive externalities of MI adoption on society. Exchange of farm labour is perceived as a negative externality (Dhawan, 2000). But, the extent of real water saving depends on climate, soils, crop type, type of MI technology and geo-hydrological environment. Similarly, the negative impact on farm labour depends on the socio-economic conditions of the region and the farming system change associated with MI adoption. However, there is hardly any research available from India to throw light on these issues.

On the other hand, many research studies in the past seem to suggest that the micro irrigation systems, particularly drip systems are viable for the farmers when the full private costs of the system are compared against the private returns. Hence, subsidies may not be desirable from an equity perspective. The reason is that it is mostly large farmers having capital who go for MI systems.

The general perception is that MI adoption leads to increase in yield (kg/ha), water saving; increase in area under irrigation due to reduction in water requirement per unit area, and advancement in produce harvest, all resulting in social benefits. But, most of these perceptions are based on research on drip irrigated farms of orchards and cash crops. Again, they looked at applied water rather than actual water consumption by the crop (Kumar et al., 2008). Also, studies concentrated in agriculturally prosperous regions where labour is in short supply. In the absence of rigorous analysis, the social benefits tend to get over-emphasized, and costs ignored.

A very recent research on drip irrigated cotton showed a 114% increase in yield and 45% reduction in applied water (Narayanamoorthy, 2008). The effect of climate, geo-hydrological environment, crop type and type of technology used were never considered in assessing the physical impacts of MI adoption on water and energy use, which determine the real economic and social benefits. The potential negative impacts MI system adoption can have on society (social cost) such as reduced labour absorption in agriculture were generally ignored, and instead the labour saving impact was highlighted as a private benefit. Part of the reason might be the fact that large-scale MI adoption takes place in regions where agriculture is progressive, and labour is in short supply. The research on the actual physical and economic benefits from sprinkler irrigation is very scanty in India (Kumar et al., 2008).

2. CONTEXT

On notable example for large-scale and intensive adoption of MI systems, is the Indira Gandhi Nahar project–Phase - I located in Bikaner district of Rajasthan. In lieu of the growing problems of water logging and salinity in the command area, and inter state conflict over sharing of water, government motivated farmers to use a local system called *diggie* to store canal water in order to make water use more efficient. The construction of the diggie enables farmers to use the water for irrigation as and when required. It also enables the use of pressurized irrigation techniques like sprinkler irrigation.

While the large scale adoption can be attributed to high returns against the investments, the subsidies being made available to the farmers play an important role in raising the net returns, there by boosting adoption. In Rajasthan, the government gives a maximum subsidy of Rs. 40,000 for constructing a *diggie*. This is in addition to the subsidy for MI systems which GoI provides. In Lunkaransar taluka of Bikaner district, farmers had adopted sprinkler irrigation for their existing crops on a large-scale. A properly designed lay-out of a sprinkler system ensures relatively uniform application of water over the field. Sprinkler systems are usually designed to apply water at a lower rate than the soil infiltration rate, so that the amount of water infiltrated at any point depends upon the application rate and time of application. But, it is important to note that the distribution efficiencies would be low in sprinkler irrigated fields, if the fields are small. This is due to high edge effects.

3. PHYSICAL AND SOCIO-ECONOMIC CHARACTERISTICS OF THE STUDY AREA

As discussed in the earlier part of the paper, the physical impacts of use of micro-irrigation technology in a particular region depends on soil, climate, geo-hydrology and crops. The economic dynamic of micro irrigation depends on the socio-economic factors, including the land-holding pattern, crops, nature of access to irrigation sources etc. (Kumar et al., 2008). Hence, it is important to discuss the physical and socio-economic profile of the region to analyze the physical impacts, and economic and social benefits of sprinkler adoption.

3.1 The Location and its Physical Environment

Bikaner is one of the desert districts situated in the north-west of Rajasthan. It is bound in the north by districts of Sri Gangbanger, on the west by Jaisalmer and Pakistan, Churu in the east and Nagaur and Jodhpur in the south-east. Jaipur, Ganganagar, Amritsar are some of the important cities near to this district. The district is situated between the latitude 27^0 11'03'' to 29^0 03' north and longitude 71^0 54' to 74^0 12' east comprising a total geographical area of 27244 sq. km.

The district's climate varies from arid in the east to extremely arid in the west. The mean rainfall of the district is 247 mm varying from 300 mm in the east to 180 mm in the west bordering Pakistan with coefficient of variability ranges from 50 to 65%. The annual potential evapo-transpiration is 1770 mm (Gheesa Lal, 1999). The mean maximum temperature ranges from 24.4^0 to 47.9^0 C and mean minimum from 7.3^0 to (-) 1.2^0 C. Frequent drought once in 2.5 years is a common phenomenon.

Soils of this district are predominately light textured, weak structured and well drained. Moderately deep to very deep, loamy sands, sandy loams and loam soils occur on the flat aggraded older alluvial plaints and flat interdunal plains. Deep to very deep, fine sandy to fine loamy sand soils occur on the undulating sandy aggraded older alluvial plains and undulating interdunal plains and very deep fine sands on the dunes.

3.2 Socio-economic Conditions

The total population of the district is 16, 73,562 (10, 79,060 rural and 5, 94,502 urban) with a density of 61 persons / sq. km. and literacy rate of 46.55% as per 2001 census. The district has 580 inhabited villages and 67 uninhabited villages. Cultivators account for nearly 45% of the workforce in the district, and agricultural labourers are only 4.6%. The other workers account for 49% of the workforce.

As per 2000-01 land use statistics, the net sown area is 45.43% of the geographical area; forest constitute 2.68%; area not available for cultivation, 8.36%, barren and uncultivable land 1.27%, permanent pasture and other grazing land 1.27%, cultivable waste 26.77%, other fallow lands 8.93%, current fallow 4.84%, respectively. The area, which is cropped twice, is only 2.84%.

Out of the 2.33 lac ha of irrigated area, 84.91% is served by IGNP canal system and rest is served by wells and tube well. Groundnuts, american cotton, guar, kidney beans (moth), bajra, green fodder are the main crops grown in Kharif season. Except bajra all other crops are cash crops. Wheat, mustard, cow-pea, are the main crops in Rabi season. Wheat is grown only for home consumption. Horticulture crops or vegetables are not grown in slightest in the region.

3.3 Indira Gandhi Nahar Project

The Indira Gandhi Nahar Project (IGNP) is one of the largest water resources projects in the world, aiming to transform the desert into an agriculturally productive region. The IGNP was conceived and executed to utilize 9,393 MCM of the 10,608 MCM of water allocated to Rajasthan from Ravi-Beas in order to convert 1.96 mha of land in the arid desert to agriculturally productive land. The project aims at drought proofing, providing drinking water, improving environmental conditions, afforestation, employment generation, rehabilitation of project affected people, livestock development and increasing agricultural production in the region. Though the project, started in 1958 and only partially complete, it has shown remarkable success. The construction of the project has been divided into two stages.

Stage I comprises a 204 km long feeder canal, having a discharge capacity of 460m^3/sec. The stage I also consists of a 189 km long main canal and 3454 km long distribution system. It is concrete lined, and serves 5.53 lac ha of cultivable command area. Of this, 4.6 lac ha area is served by pumping with a 60m lift.

Stage II comprises a 256km long main canal and 5,606 km long lined distribution system, and serves 14.10 lac ha of CCA (873577 ha area in flow and 537018 ha under lift), utilizing 4,930 MCM of water annually. The stage II area has been divided into 7 regions. As of now 2, 33,850 ha of cultivable land in Bikaner are coming under this canal system. According to Central Water Commission: "Indira Gandhi Canal was built at a cost of Rs.70 crore. But now the income generated is about Rs. 700 crore every year from the project. An outlay of Rs. 70 crore has brought about a return of Rs. 700 crore, 10 times more. The life pattern of the people in this area has also dramatically improved."

The problems of vertical drainage of water in IGNP command area are quite well known. This is created by the occurrence of impervious layer between the water table aquifer and deep aquifers. Gypsum-Ferrous layer is present just below the surface layer of soil. It is an impervious layer and it is very thick. As the soil of the area are coarse textures with a significant amount of sand resulting in low water holding capacity. The percolated water is deposited over the gypsum-ferrous layer and as a result stagnation of water has been increased considerably. The evaporation of this water is possible because of the capillarity action of sand dunes; this is the prime reason of the salinity of the land.

3.4 Reason for Sprinkler Adoption

Three factors have contributed to sprinkler and diggie adoption. They are presence of upland, which cannot be watered by flow irrigation from canals; sharp reduction in water availability; and availability of subsidy for purchase of sprinklers and construction of *diggie*. Since there has been a remarkable reduction in the supply of canal water, the timeliness of water availability reduced, affecting the quality and reliability of irrigation. Here, the *diggies* act as an intermediate storage system for the water. The *diggie* and the pumping devise together increase their ability to improve the quality and reliability of irrigation. Although the farmers are not able to irrigate the land adequately, they can now irrigate more land both by virtue of the pressurizing device. Subsidies also act as a motivation for the farmers to adopt the MI system.

4. OBJECTIVES AND METHODOLOGY FOR THE STUDY

4.1 Objectives

The objectives of the study are: to analyze the farming systems changes associated with MI adoption in Indira Gandhi Canal command area; and to evaluate the economic and social cost benefits of micro irrigation adoption in the region.

4.2 Methodology

Generally, the variable affecting the economic dynamic of micro irrigation adoption in Bikaner region are: i] change in crop yield; ii] change in area under irrigation; iii] change in cost of crop cultivation; and, iv] change in value of the produce (Dhawan, 2000). But, how these variables get altered depends on the socio-economic conditions of the farmers and the region under consideration, the climate and the geo-hydrological environment (Kumar, 2007). In the following section, we would discuss how each one of these variables had been altered due to sprinkler irrigation.

Often in the context of MI, the reduction in water applied due to prevention of deep percolation is counted as a private benefit. But, as Dhawan (2000) cautions, such private benefits can be over-emphasized in situations where the deep percolation appears as return flows to the shallow aquifer and recharge to the well. Nevertheless, such private benefits are applicable in situations where farmers are confronted with marginal cost of using water. Since, the farmers here are not paying for canal water on volumetric basis, changes in volumetric consumption of water due to adoption of micro irrigation system does not lead to cost saving for the farmers.

But, in regions of water shortage, the social benefits due to water saving could be enormous. But, the actual social benefit depends on the extent of real water saving, rather than saving in applied water (Dhawan, 2000). Real water saving comes from reduction in non-beneficial evaporation from soil, and non-recoverable deep percolation (see Allen et al., 1998 for details). Real water saving due to MI depends on several physical factors (Kumar et al., 2008). In regions, with semi-arid and arid climatic conditions and light textured soils and deep water table conditions, the real water saving comes from reduction in non-beneficial evaporation and non recoverable deep percolation (Kumar et al., 2008). Again, since return flows create water logging and soil salinity problems, it can be treated as non-beneficial depletion of water. Hence, in the present condition, the applied water saving can be treated as real water saving.

4.2.1 Sampling frame, and method of data collection

The universes of sampling were the villages of Lunkaransar taluka of Bikaner district. Four villages Rozha, Phuldesar, Bada Delana and Chota Delana were selected. The farmers were selected randomly. A group of 30 farmers who had adopted *diggies* and use sprinkler irrigation and 30 other farmers who have not adopted *diggies* and use sprinkler irrigation were chosen for the analysis.

Structured interview using questionnaire were conducted. Based on the questionnaire the data on the cost and benefit components of crop cultivation were collected. The main constituents of cost components are, inputs viz., fertilizers, manure, seeds; labour cost; transportation; cost of maintenance of MI system; and water charges. The crop returns are, the main product; and the by-product (for wheat, cluster bean and groundnut); and fodder.

4.2.2 Analytical procedure

The social cost-benefit of micro irrigation adoption was evaluated by taking the ratio of the sum of private benefit and positive externalities associated with MI adoption and the sum of private cost of MI adoption and the negative externalities associated with adoption. On major assumption involved in the evaluation of both positive and negative externalities associated with MI adoption is that the externalities are a linear function of the area irrigated.

The variables to be considered for evaluation of social costs and benefits were decided after preliminary field investigations. These investigations provided insights into the nature of positive and negative externalities associated with sprinkler adoption. Reduction in the amount of water consumed for crop production was identified as a major positive externality. Expansion in the irrigated area and the proportional increase in crop yield were identified as major private benefits of sprinkler adoption. This is contrary to what has been found in most cases due to adoption of MI systems.

The private benefit-cost ratio for sprinkler irrigated crops was evaluated by taking the ratio of the difference between the aggregate net private return from all the sprinkler irrigated crops and the aggregate net private returns from all the flood irrigated crops prior to adoption for the same water supply conditions (as post adoption); and the sum of annualized capital cost and annual operation and maintenance of the systems (C_{SPRINK}). Both numerator and denominator were estimated per unit area of the sprinkler system. This can be expressed mathematically as:

$$B-CRatio=\frac{[\sum_{i=1}^{m} NR_{SPRINK_i} * ASUM_{SPRINKi} - RF * \sum_{j=1}^{n} NR_{FMI_j} * ASUM_{FMIj}}{C_{SPRINK}} \quad \text{….} \ (1)$$

Here, $$RF = \frac{[\sum_{j=1}^{n} V_j]}{[\sum_{i=1}^{m} V_i]} \quad \text{…………….} \ (2)$$

Here, $NR_{SPRINK,i}$ and $NR_{FMI,j}$ are the weighted averages of the net private return for all the farmers growing sprinkler irrigated crop i, and flood-irrigated crop , respectively. $ASUM_{SPRINK,i}$ is the sum of the area under crop i from all the sprinkler adopter farmers in the sample. $ASUM_{FM,j}$ is the sum of the area under crop j, which is flood-irrigated, from all farmers. Here , and V_j are the volume of water allocated to crop i by all farmers in the sample using sprinkler irrigation, and allocated to crop j by all farmers using flood irrigation, respectively.

Water saving benefit through sprinkler adoption (Δ_{SPRINK}) is the difference between the amount of water that is actually needed to produce the current economic outputs from the farms under traditional method and the actual amount of water used for production currently.

$$\Delta_{SPRINK} = \frac{[\sum_{i=1}^{m} NER_{SPRINK,i} ASUM_i}{[\sum_{j=1}^{n} \theta_{FMI,j} * V_j / \sum_{j=1}^{n} V_j]} - \frac{[\sum_{i=1}^{m} NER_{SPRINK,i} ASUM_i]}{[\sum_{i=1}^{m} \theta_{\overline{SPRINK},i} * V_i / \sum_{i=1}^{m} V_i]} \quad \text{.........} (3)$$

Here, $NER_{SPRINK,i}$ is the net economic return from the sprinkler irrigated crop i. $\theta_{FMI,j}$ is the water productivity for crop j in economic terms under flood method of irrigation. $\theta_{SPRINK,i}$ is the water productivity for crop i in economic terms using sprinklers. Water productivity is estimated using the functional formula, by dividing the net returns from crop production and the volume V_i of water applied.

The positive externality induced by sprinkler use for irrigation through water saving is estimated by multiplying the average volume of water that can be saved from unit area under sprinkler irrigation, and the average net return under flood-irrigated crop from unit volume of water (it is same as the overall net water productivity for flood-irrigated crop). Mathematically, it can be expressed as:

$$\left[\frac{\sum_{j=1}^{n} NR_{FMI,j} ASUM_j}{\sum_{j=1}^{n} V_i}\right] * \frac{\Delta_{SPRINK}}{\sum_{i=1}^{m} ASUM} \quad \text{........................} (4)$$

The social benefit-cost ratio is estimated by taking the ratio of the sum of private benefit +positive externality and the sum of private cost and negative externality. This is basically adding up of Equation (1) and Equation (4).

The net water productivity in relation to applied water for different crops under flood method of irrigation were estimated by taking the ratio of net return from crop production and the total volume of irrigation water applied. Similarly for sprinkler irrigated crop, the net water productivity was estimated by taking the net return and the volume of water applied through sprinklers[1]. Here, it is assumed that the rainfall contribution of yield is negligible, and that the entire yield comes from irrigation only.

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[1] The volume of water applied through sprinklers for each plot was estimated by multiplying the average number of sprinklers for a unit area of plot, with the discharge of the sprinkler, number of irrigations, the hours of irrigation per watering and the area of the plot.

5. ANALYSIS AND RESULTS

5.1 Changes in Crop Inputs

Comparison of data on crop inputs for flood irrigated crops and their sprinkler irrigation counterparts was done for the four main inputs, viz., seed quantity, irrigation dosage, fertilizer and pesticide. The results are presented in Table 1. It did not show any significant change in the level of inputs except for irrigation. Under sprinkler method, farmers increased the frequency of irrigation for all crops. Though the duration of watering also increased with sprinklers for all the crops, this was due to low rate of water delivery through the sprinklers. But, closer analysis using data on discharge rates showed major reduction in water application depth under sprinkler irrigation.

Table 1: Comparison of Crop Inputs during Pre and Post Adoption of Sprinklers

Crop	Crop inputs before adoption of sprinkler					Crop inputs after adoption of sprinkler				
	Seed (kg)	Irrigation		Fertilizer (kg)	Insecticide (Rs.)	Seed (kg)	Irrigation		Fertilizer (kg)	Insecticide (Rs)
		No.	hr.				No.	hr.		
Kharif										
Cluster Bean	14.3	1.0	1.5	0.0	283	13.1	2	5.8	0.0	292.0
Groundnut	87.3	4.5	4.3	DAP-54 U-94.2	0.0	83.2	6.8	7.2	D-53.2 U-92.1	0.0
Cotton	13.5	5.4	4.9	DAP-90 U-180	90	12.4	5.6	7.0	D-82.8 U-165.6	144.0
Green Fodder	7.8	1.0	1.2	0.0	0.0	7.8	2.1	4.4	0.0	0.0
Black Gram	15	1.0	1.2	0.0	0.0	15.8	2.6	5.4	0.0	0.0
Rabi										
Wheat	74.3	5.8	4.8	DAP-84 U-176	0.0	72	8.4	8.2	D-86 U-172	0.0
Mustard	4.3	3.4	4.4	DAP-54 U-92	0.0	4	5.8	7.2	D-53 U-92	0.0
Cow Pea	23	1.3	2.8	34	0.0	23	2.9	6.2	D-31	0.0
Green Fodder	8	1.2	1.6	0.0	0.0	7.8	2.3	3.9	0.0	0.0

Source: Authors' own analysis using primary data

5.2 Changes in Crop Yield Due to Sprinkler Adoption

Generally, it is believed that use of micro irrigation systems result in increase in yield due to uniform application of water across the field resulting in more uniform distribution of soil moisture, and uniform growth; frequent application of smaller dosage of water to the crop resulting in lower chances of moisture deficit and water stress, particularly prevention of moisture stress at critical stages of crop growth; optimum dosage of irrigation in each watering, preventing chances of nutrient leaching. But, in the IGNP command area, no trend was found vis-à-vis the crop yield change due to sprinkler adoption.

The major kharif crops that are grown in Lunkaransar taluka are groundnut, cluster bean, bajra and green fodder. The yield figures for these crops before and after adoption of sprinklers are compared and presented in Table 2. It shows that there has not been a substantial change in the yield after adoption. In case of groundnut and cluster bean, yield has decreased marginally where as for bajra it had increased marginally. Over all there is no general trend in yield. While the effect of sprinkler irrigation on yield could be both positive and negative, the availability of rains during kharif season can nullify this effect.

Table 2: Impact of Sprinkler Use on Yield of Kharif Crops

Name of Crop	Crop Yield Under		Percentage change in yield (+/-)
	FMI (qtl/ha)	Sprinkler irrigation (qtl/ha)	
Groundnut	21.74	21.38	-1.65
Cluster bean	12.76	12.60	-1.25
Cotton	22.20	22.20	0
Bajra	15.30	22.20	45

Source: Authors' own analysis using primary data

Note: + indicates increase after adoption; "-" indicates decrease in yield after adoption

The major winter crops that are grown in Lunkaransar taluka are wheat, mustard, pea and green fodder. The crop yields are compared and presented in Table 3. It shows that the yield of green fodder has increased substantially where as that of wheat had decreased. There was marginal improvement in the yield of mustard. The yield reduction for wheat can be attributed to the poor distribution uniformity in watering which affect the crop growth adversely. It is to be kept in mind that the input factors that can potentially affect the yield, other than irrigation, had not changed after adoption. What is to be inferred is that the effect of poor distribution uniformity is much higher than that of improved quality and reliability of irrigation.

Table 3: Impact of Sprinkler Use on Yield of Winter Crops

Name of Crop	Crop Yield Under		Percentage change in yield (+/-)
	FMI (qtl/ha)	Sprinkler irrigation (qtl/ha)	
Wheat	24.43	23.10	-5.44
Mustard	14.53	14.82	1.99
Cow Pea	9.39	9.39	0
Green Fodder	55.44	64.80	16.88

Source: Authors' own analysis using primary data

5.3 Changes in Area under Crops and Irrigation

In well irrigation, there are no limits on the amount of water farmers can access, except those imposed by the aquifer characteristics and energy supply. But here, in this case, canal water supply is restricted, and the amount of land which farmers can irrigate is constrained by the amount of canal water. In the case of IGNP, the water availability from canals was adequate to bring all the operational holdings under flood method of irrigation. But due to undulating terrain and higher elevation, a significant portion of the land, which cannot be irrigated through gravity flow, had to be left fallow.

But, as farmers in the area experienced drastic reduction in water supply from canals, they had to resort to more efficient method of water application even to maintain the previous levels of irrigation. The availability of subsidies for construction of *diggie* enabled use of sprinkler irrigation. With the adoption of sprinklers, the farmers could also bring a lot of the undulating land lying in higher elevation, under irrigation. We would examine the changes in area under irrigation for Kharif and Rabi crops.

Table 4 shows that the total area under Kharif crops experienced a very marginal increase of 1.7 ha. Groundnut and cluster bean area increased slightly, and more importantly, the area under irrigation increased for both the crops. The significant change due to adoption is that more area is put under irrigation. There are three major reasons for this increase. First: framers receive remunerative prices for this crop. Second: the agro-climate is very favorable for the cultivation of groundnut. Third: sprinkler is very suitable for irrigating groundnut. The area under irrigated cluster bean saw an increase of 12%; and the absolute increase in area (7.5 ha) is also quite substantial. This is because cluster bean does not require much water and is mostly rain-fed. Even prior to adoption of sprinkler, the area under cluster bean was quite high.

In the case of cotton, the area under cultivation was also not very large prior to adoption. No change in area under this crop was seen after adoption. It is also to be noted that cotton is not amenable to sprinkler irrigation.

Table 4: Impact of Sprinkler Adoption on Area under Kharif Crop

Name of crop	Area under cultivation before adoption (ha)	Area under cultivation after adoption (ha)	Irrigated area before adoption (ha)	Irrigated area after adoption (ha)
Groundnut	41.39	43.33	41.39	43.33
Cluster bean	136.94	136.12	53.06	60.56
Cotton	6.39	6.39	6.39	6.39
Black Gram	2.78	2.78	0.00	0.00
Bajra	3.05	3.62	2.50	3.06
Green fodder	1.68	1.68	0.00	0.52
Total	192.23	193.92	103.34	113.86

Source: Authors' own analysis based on primary data

As regards winter crops, as Table 5 indicates, there has been some increase in the area under cultivation of there crops, namely wheat, mustard and cow pea. Area under wheat had increased by 0.80ha. The main reason for this increase is that before adoption of MI system the staple food crop of the area was bajra, but with time wheat has become the staple crop, indicating a general improvement in the welfare of the people. This is in spite of the yield reduction after adoption of sprinklers. Farmers grow it only for domestic consumption. Perhaps the reason is that wheat is a water intensive crop.

Table 5: Impact of Sprinkler adoption on Area under Winter Crop

Name of Crop	Area under cultivation before adoption (ha)	Area under cultivation after adoption (ha)	Irrigated area before sprinkler adoption (ha)	Irrigated area after sprinkler adoption (ha)
Wheat	28.61	29.44	28.61	29.44
Mustard	35.00	37.78	33.891	36.68
Cow Pea	48.33	49.72	32.78	32.78
Green fodder	3.62	3.62	3.33	2.78
Fennel	1.39	1.39	1.39	1.39
Total	116.95	121.95	100.00	103.07

Source: Authors' own analysis based on primary data

The area under mustard has also increased by 2.78 ha (8%). The main reason for increase in the area for mustard is the high returns. Also, the yield was found to be improving with sprinkler use for this crop. The farmers are able to sell the mustard for attractive price. There was increase in the area under cultivation of cow pea also, but the irrigated area did not increase. The total increase in area under cultivation is 4.3% and that under irrigation is 3.1%. In the case of green fodder, the irrigated area decreased by 0.55 ha.

One could argue that change in area under crops in such plots cannot be attributed to sprinkler adoption. But, given the fact that the rainfall is quite low, during droughts these crops also will have to be irrigated. The absence of proper water lifting and irrigation device prevents farmers from taking crops in these plots as the investment for crop inputs would be lost in situations of droughts. But, the access to storage system and the sprinkler technology enables the farmers to take crops in plots which otherwise cannot be irrigated under gravity. Hence, this is a positive externality of sprinkler and *diggie* adoption.

5.4 Impact on Livestock Rearing

Livestock forms the organizing feature of the region's farming system. The farmers of the area keep cow, buffalo, goat and camel. The number of livestock per family ranges from 2 - 20. The livestock holding per family had remained more or less constant over the past many years. When the animals give birth to new ones, the farmers either sell either the calf or the older animals according to the need.

The farmers keep cows and buffalos mainly for dairying. The average production of milk per animal in the area varies from 2 - 5 lt/day. The farmers own only the local breed of animals. The amount of feed supplied to the animals varies from 10 -15 kg/animal each time, with a two-time feeding generally practiced. The fodder is available from within the farm. It includes both green and dry fodder. The residents of the area do not buy milk from the others. They meet their household milk demand from their cows and buffaloes. The excess milk is sold to either the local trader, who makes mawa out of it, or to Urmul diary. The price of milk varies from Rs.10 - Rs.12/lt. The farmers also keep camels for ploughing and transport.

The area used to face severe seasonal fodder shortages in the past. To overcome this, a practice that was prevalent in the area till a few years ago is that during scarcity, one or two persons from the village would collect the cattle from the entire village. These animals would be taken to the neighbouring state of Punjab where plenty of green fodder is available. These animals are taken back to the villages only with the onset of monsoon season when sufficient amount of fodder is available locally. Now-a-days, with the introduction of IGNP waters, farmers produce fodder in their own farms and the shortfall is met through purchase from the local market. Under conditions of water shortage, it is the use of sprinklers which enables the farmers to sustain the area under fodder crops and also those crops which have byproducts that can be used as fodder. This can be treated as a positive externality of sprinkler adoption.

5.5 Impact of Sprinkler Adoption on Crop Water productivity

Water productivity in crop production can be defined in terms of biomass production for every unit of water used or the net income return per unit of water used. The crop water productivity could be estimated either in relation to the amount of water applied (applied water productivity); or the amount of water consumed by the crop (productivity of consumed water ET) or the total amount of water applied, i.e., irrigation plus the effective rainfall (Kijne et al., 2003). Water productivity in crop production could be manipulated by improving the crop (biomass) output through crop management involving agronomic practices, nutrient management or crop technology management, or by reducing water use through on-farm water management[2].

Table 6 shows that the water productivity for ground nut, cluster bean, mustard and pea are high and for wheat and green fodder is lower under both flood-irrigation and sprinkler irrigation. The reason for high

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[2] On farm water management can be through any of the following measures: i] reducing conveyance losses in irrigation water delivery; ii] applying optimum dosage of water; iii] ensuring water application at critical stages of crop growth; and iv] efficient use of rainwater. First and second measure reduces non-beneficial depletion. The third measure increases the yield response to ET; and the fourth measure reduces the irrigation water requirement and total water depletion.

productivity of mustard is that the income per unit of land is high (Rs.22000/ha), and is low water-consuming. The reason for low water productivity of wheat is that it is a water intensive crop and takes nearly 2-3 times more water than mustard, while the net returns is more or less same as that of mustard.

Table 6: Applied Water Productivity of Kharif and Rabi Crops under Sprinkler and Flood Irrigation

Sr. No.	Name of crop	Applied water productivity (Rs/m^3) under sprinkler	Applied water productivity (Rs/m^3) under flood irrigation
	Kharif Season		
1	Ground Nut	24.24	10.24
2	Cluster Bean	34.00	18.27
3	Cotton	13.86	8.31
4	Bajra	10.47	5.55
	Rabi Season		
1	Wheat	8.38	4.19
2	Mustard	20.23	6.69
3	Green Fodder	7.74	4.68
4	Cow Pea	25.49	8.72

Source: Authors' own estimates based on primary data

Water productivity for cluster bean is also very high. The reason being it requires only 1-2 irrigations. Despite being a water-intensive crop, water productivity for groundnut is high. The reason is that the net return from this crop under both flood and sprinkler irrigation (Rs.43700/ha and Rs.35500/ha, respectively) is highest among all the crops grown. The slight increase in area under cultivation for mustard from 35 ha to 93.33 ha (see Table 5) is a clear indication that the farmers use there land efficiently so that they can get the maximum returns out of that.

Comparison between sprinkler-irrigated crops and flood-irrigated crops shows that the water productivity values are higher under sprinkler irrigation for all the 8 crops. For the remaining crops, since farmers have not irrigated, the estimates of irrigation water productivity are not available. The difference is quite substantial for cluster bean, ground nut and cow pea. The enhancement in water productivity has mainly come from the reduction in applied water in the case of sprinkler irrigated crop rather than enhancement in net returns. We would see in the subsequent section that the net returns are much higher under flood irrigation for most crops. In the case of cluster bean, cow pea, green fodder and bajra, some farmers were found to be growing the crop under rain-fed conditions. For these crops, those farmers who are irrigating these crops are only considered for water productivity estimates.

5.6 Incremental Economic Benefits from Sprinkler Adoption

Past research on economics of micro irrigation were for well irrigators. Two important considerations were involved in the analysis. They are: i] increase in net crop return from unit area of micro irrigated plot over that irrigated using conventional method; and, ii] potential return from the additional area that could be brought under irrigation using the water saved through use of micro irrigation. While the first is realistic, the second consideration assumes that physical scarcity of water does not permit the farmers from expanding the area under irrigation prior to adoption. Such analyses were not based on any field evidence of area expansion due to MI adoption. Such considerations are valid for situations where wells are the source of water.

But, here, canal is the only source of irrigation water for the farmers, in which case the amount of water which farmers can access is limited. Under such situations, the criteria for assessing the economic performance should be: increment in aggregate return from all the crops that are irrigated with sprinklers, including the expanded area. Here, the validity of the assumption about area expansion can be tested. Unfortunately, the farmers experienced a major cut in the volumetric water availability, which prompted them to go for diggie construction and sprinkler irrigation for their crops. Hence, comparing the net return from sprinkler irrigated crop area against the flood-irrigated crop areas does not make sense. The volume reduction should be factored into the area under conventional method of irrigation to make the comparison realistic.

Using equation (2), we have estimated the total amount of water used by the farmers in our sample both prior to and after adoption of sprinkler system. The difference was quite substantial and it corroborated with what farmers reported. While the total water use was 0.638 MCM before adoption of sprinkler, it was reduced to 0.237 MCM, which forced farmers to go for micro irrigation. The reduction factor was estimated to be 0.371.

To begin the economic analysis, the net income return per unit area of land was worked out for all the irrigated crops for both flood method of irrigation and sprinkler method of irrigation. The results are presented in Table 7. It graphical representation is given in Figure 1.

As Table 7 indicates, the mean values of net return per ha of the crop is much higher under flood irrigation for four crops, and lower for three crops. Further, the average reduction in net return per unit area for the first set of crops is higher than the average rise in return for the second set of crops. This does not mean that the aggregate returns would be lower under sprinkler irrigation. The reasons are many: 1] every farmer grows more than one crop in each season; 2] the net outcome of sprinkler adoption in terms of change in net return would depend on how much area the farmer allocate to each crop. Nevertheless, it is important to note that comparative income return won’t be an important consideration for farmers to go for sprinkler irrigation. The reason is the water supply situation had changed. With heavy rationing of water, the productivity of water would become the most important consideration for farmers rather than returns from unit area of land.

Table 7: Net Return from Different Kharif and Rabi Crops under Flood and Sprinkler Method of Irrigation

Sr. No.	Name of crop	Net return (Rs/ha) of land under	
		Flood irrigation	Sprinkler irrigation
	Kharif Crops		
1	Groundnut	43693.0	35538.0
2	Cluster Bean	23960.0	16110.0
3	Cotton	36586.0	21959.0
4	Bajra	6644.6	6633.0
	Rabi Crops		
1	Wheat	23637.0	17497.0
2	Mustard	22012.0	24054.0
3	Green Fodder	6165.0	6790.0
4	Cow Pea	11618.0	12330.0

Note: the net return is exclusive of the cost of sprinkler system

The economic returns from sprinkler irrigation were estimated using the figures of aggregate incremental returns from sprinkler irrigated plots over plots irrigated under conventional method of irrigation (0.371*203.37ha). The incremental return per unit area was deduced from this figure based on the figure of the total area under sprinkler irrigation (215.57ha). This was compared against the incremental cost of the sprinkler per unit area covered by the system (Rs.7519.8/ha). The incremental return was estimated to be Rs. 15937/ha. Hence, the private cost-benefit ratio for the system is Rs. 2.11. The reason for the high benefit-cost ratio is the unique characteristic of the system itself. The system is movable, and with just with an extra HDPE pipes to be used as main pipe, the same set could be used to irrigate large area, provided sufficient labour is available.

Figure 1: Impact of Sprinkler on Land Productivity (Rs./ha)

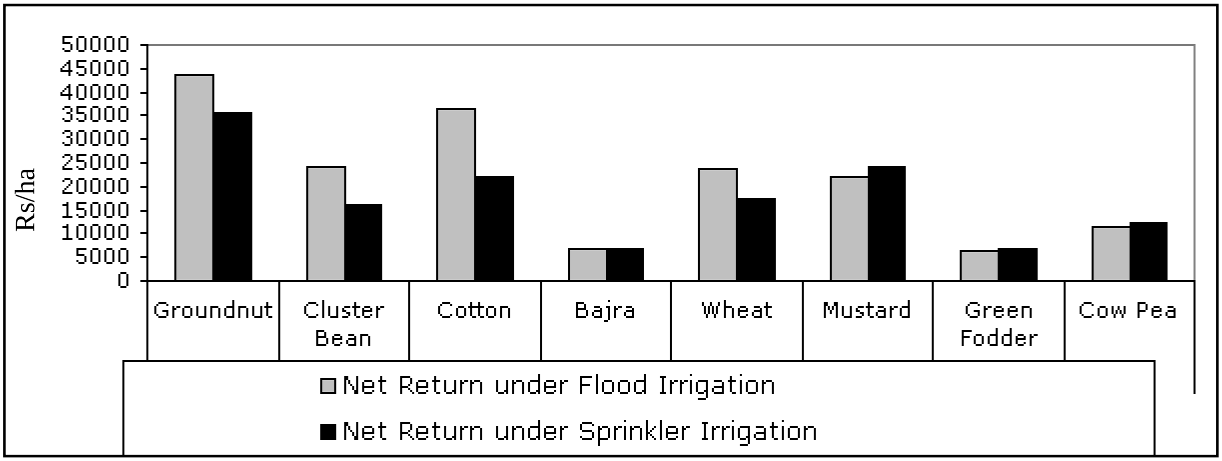

Table 8 shows that the net return from sprinkler irrigated crops (Rs. 53.74 lac-row 3, column 3) is slightly higher than that of flood-irrigated crop (Rs. 52.25 lac). The net incremental return per ha is negligible, and is far less than the additional cost which farmers have to incur for sprinklers, which is Rs.7519.8/ha. But, if we consider the fact that the volume of water available for crop production has been much lower for the post adoption scenario, the effective incremental return from sprinkler-irrigated crops becomes Rs.15937/ha. The positive incremental return is mainly due to the effective increase in area (see numerator of Equation 1 in methodology section) from 75.44ha - 215.57ha. Table 8 shows that both the private cost benefit ratio and economic benefit cost ratio are more than 1.0. Hence, it can be concluded that farmers would have incentive to adopt the systems even if subsidies are not available.

Table 8: Private Costs and Benefits from Sprinkler Irrigation

Sr. No.	Attributes of costs and benefits of sprinkler irrigation	Amount in Rs.	
		Aggregate	Per ha
1.	Net Return from Crops Irrigated by FMI (Rs)	5225368.80	
2.	Net Private Return from Sprinkler Irrigated Crop (Rs)	5374196.00	
3.	Incremental Return after Sprinkler Adoption	148827.00	
4.	Annual Incremental Private/Economic Returns due to Sprinklers (Rs) (2)-(1)*0.371	3435584.50	15937.2
5.	Annual Incremental Private Cost (Capital and O & M)	1621033	7519.8
6.	Annual Incremental Economic Cost (Capital and O & M)	1801605	8357.4
7.	Private B-C Ratio		2.11
8.	Economic B-C Ratio		1.90

Source: Authors' own analysis based on primary data

Note: the sprinkler irrigated area is 215.57ha out of the 314.48ha under crops; the total cost of sprinklers and diggies is Rs. 43.5 lac without subsidy and Rs.31.5 lac with subsidy for the entire sprinkler irrigated area. The annualized capital cost (both private and economic) was worked out using a discount rate of 10% and a life of 10 years for the system. The total annual operation and maintenance cost of the motor, sprinklers and the diggie was estimated to be Rs. 11.32 lac rupees for the entire sprinkler irrigated area.

5.7 Social Benefits due to Sprinkler Adoption

The most significant social benefit in the region due to adoption of sprinkler irrigation is real saving in irrigation water. This is in view of the scarcity value of the resource being acutely felt in this arid region with growing competition from other sectors such as industry and urban drinking, in addition to that from farmers in other parts of IGNP command. The non-adoption of sprinkler irrigation would have forced the farmers to either tap groundwater to sustain the income from crop production or led to conflicts.

As regards the potential social costs, no major negative externalities were seen to have been induced by sprinkler adoption in the area. The potential negative externalities, as evident from a recent study in Nalgonda district of Andhra Pradesh, are: 1] reduced labour absorption in agriculture, mainly coming from replacement of labour-intensive crops by cash crops which depend on mechanized farming, and decline in wage rates due to the reduction in labour demand; and 2] increase in food prices due to decline in cereal production in the area mainly due to replacement of traditional food crops by high valued cash crops. But, in the case of IGNP, no major change in cropping pattern that could affect cereal production was found. Also, there was no positive or negative impact on either labour demand or wage rate after technology adoption.

Ideally, the aggregate water saving due to adoption depends on the real water saving at the field level per unit area through MI adoption; and what economic value could be generated from the saved water. We have already estimated the reduction in water use at the aggregate level for the sample farmers through MI adoption to be 0.401MCM (i.e., 0.638-0.237=0.401). But, for the purpose of social cost benefit analysis this figure will not make sense. The reason is that the yield and income figures corresponding to pre and post adoption scenarios were different. Hence, it is imperative to know how much water could have been used up by the farmers to generate the return that occurs from the sprinkler-irrigated plots, had they used the conventional method of irrigation.

We had employed equation (3) to estimate this. This uses net private return from sprinkler irrigated crop, and water productivity (Rs/m^3) estimates for all the crops under the two different methods of irrigation to estimate the hypothetical water consumption for generating returns using FMI, and the current water consumption. The net income return from sprinkler irrigated area is estimated by taking the gross returns from all the sprinkler irrigated crops and the total cost of all inputs, including the full cost of sprinkler systems. This was estimated to be Rs. 35.72 lac. The overall net water productivity of all the crops irrigated under flood method of irrigation was estimated to be Rs. 8.63/m^3. The amount of water needed to generate the said income returns from flood irrigated crops is estimated to be 0.413MCM. Hence, the water saving is 0.163MCM (i.e., 0.413-0.237=0.176MCM).

This means, every hectare of sprinkler irrigated area saves water to the tune of 816m^3. Had the farmers not used sprinkler irrigation, they would have been forced to depend on tube wells for maintaining the current level of farm returns. Hence, the water saving can be treated as real. If we assume that the farmers allocate the saved water to put additional area under irrigation using flood method, the additional income that can be generated from one cubic metre of water would be Rs.8.63. Hence, the surplus value product associated with the positive externality induced by sprinkler adoption per ha is Rs.7045. As Table 9 indicates, the social benefit cost ratio is 2.75. This means, subsidies in sprinkler irrigation could be justified.

Table 9: Private Costs and Benefits from Sprinkler Irrigation

Sr. No.	Attributes of costs and benefits of sprinkler irrigation	Amount in Rs/ha
1.	Annual Incremental Economic Cost of Sprinkler & Diggie	8357.00
2.	Annual Incremental Benefit (Rs.) (from Table 6)	15937.20
3.	Total Water Saving per ha of Sprinkler-irrigated Area due to Technology (m^3)	816.00
4.	Positive Externality due to Water Saving	7045.00
5.	Social Cost-benefit Ratio (2)+(4)/(1)	2.75

Source: Authors' own analysis based on primary data

6. FINDINGS

1. One major consequence of sprinkler adoption in Bikaner is slight expansion in area under irrigation from 203.33ha to 215.57ha. This is in spite of reduction in volume of irrigation water available to the farmers to an extent of 62.9%. Hence, the real area expansion benefit due to sprinkler adoption has to be seen from a hypothetical pre-adoption area of 75.44ha.

2. In many regions, MI system adoption is associated with introduction of new high valued fruit and cash crops that replace traditional food crops or change in cropping pattern towards high valued crops, with impacts on food security, use of animal power for cultivation and labour absorption. But, in Bikaner, no major change in crops or cropping pattern is observed. Hence, there are no major negative externalities.

3. With sprinkler adoption, the yield of mustard, bajra and winter green fodder had increased marginally, while that of wheat, groundnut and cluster bean had decreased marginally. Sprinkler and diggie use could impact on yield both positively and adversely, the first due to improved quality and reliability of irrigation, and the second due to reduced distribution uniformity. But, the farmers seem to take advantage of reduced water requirement by allocating more area to those crops which gain in terms of yield through sprinkler use.

4. The mean values of net return per ha of land was lower under sprinkler irrigation for four crops, while it was slightly higher for three other crops. But, farmers could manipulate the aggregate returns by allocating more land to such crops which give relatively higher net income per unit of land. Nevertheless, aggregate net return won't be the consideration for farmers to decide in favour of sprinkler irrigation. The reason is the changed water supply situation under which they would try and maximize the return per unit of water.

5. The net water productivity for all the crops is higher under sprinkler irrigation than under flood irrigation. The improvement has mainly come from reduction in applied water use achieved through reduction in conveyance loss and deep percolation loss, rather than improvement in net income.

6. The private returns from sprinkler-irrigated crops under the scenario of reduced water availability are far higher than the returns that could have secured if the farmers continued with the traditional method of irrigation under the same scenario of water availability. The net incremental benefit was estimated to be Rs. 15937/ha. This means, the opportunity benefits of adoption are very high. Hence, adoption of sprinkler with *diggie* is economically viable for the farmers. The private benefit-cost ratio is 2.11.

7. But if we consider the actual cost of construction of the *diggie* and the actual price of sprinklers, the system gives net returns slightly lower than that under flood method of irrigation. The economic benefit-cost ratio is 1.90. This means that farmers can adopt the system even without subsidies.

8. As regards the positive externality induced by large-scale sprinkler use on society, the main benefit is from water saving. The aggregate income benefit due to sprinkler use for an area of 215.2 ha is equivalent to using an additional 0.176 MCM of water for generating the same economic output from flood-irrigated crops. Hence, the water saving is 0.176MCM. Another positive externality is on the impact on livestock.

9. The positive externality of water saving per ha of sprinkler adoption is 816m3. This is equivalent to an economic surplus of Rs. 7045/ha if we assume that the farmers use the saved water to grow the same crops with flood irrigation. Hence, the social benefit due to sprinkler adoption is Rs.22982/ha. The incremental cost to the society is Rs.9734.8/ha. Hence, the social benefit-cost ratio is 2.75. Hence, the subsidies for diggie and sprinkler system could be justified.

7. CONCLUSION

The study shows that sprinkler with diggie is economically viable for the farmers even without subsidies. It further shows that the social benefits exceed the social costs. The present study had shown that incremental income return over pre-adoption scenario will not be the consideration for farmers to go for micro irrigation systems under situations of induced water scarcity. Instead, they would be concerned with enhancement in productivity of water, which also ensures that the income returns are higher than what they would probably secure under conditions of reduced water availability, with flood-irrigated crops. Since the social costs are less than the social benefits, the subsidies are justifiable as it makes the private benefits exceed the private costs. The study also validates the unique methodology used for economic cost benefit analysis of micro irrigation systems. On the social cost benefit front, we have only considered the positive externality associated with water saving. The other positive externality of sprinkler adoption is reduced risk in livestock keeping. However, we had not quantified this.

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