Ind. Jn. of Agri.Econ.
Vol.65, No.3, July-Sept. 2010

Can Drip Method of Irrigation be Used to Achieve the Macro Objectives of Conservation Agriculture?

A. Narayanamoorthy*

I

INTRODUCTION

Intensive agriculture practiced presently throughout the world has not only degraded the quality of soil, water and genetic resources but also depleted them. Soil tillage by plough and hoe followed both in developing and developed countries has also degraded the land leading to declining productivity levels and increasing the cost of production (Garcia-Torres *et al.,* 2003). It leads to the reduction in the content of organic matter in soil which in turn leads to widespread soil erosion and nutrient mining as well. Conservation agriculture, which is "a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production level while concurrently conserving the environment", is expected to improve the soil quality as well as help optimising the yields and profits from agriculture (www.fao.org). Conservation agriculture is gaining acceptance all over the world including India in recent years because of its potential in solving the looming food security and livelihood opportunities of the farmers particularly those belonging to the economically weaker sections.

There seems to be a close linkage between conservation agriculture (CA) and the drip method of irrigation used for crop cultivation, but somehow it has not been explicitly highlighted in the literature on conservation agriculture. Drip method of irrigation was primarily introduced as a water conserving technology. However, its macro objectives are closely matching with that of conservation agriculture. CA is based on the principles of upgrading the soil and optimising the inputs for crop production, including labour and profits. It also advocates that "the combined social and economic benefits gained from combining production and protecting the environment, including reduced input and labour costs, are greater than those from production alone" (Dumanski *et al.,* 2006). CA minimises the disturbance of the soil by tillage, promotes the only required and balanced application of chemical inputs careful management of residues and wastes. The practices followed under CA are

*Professor and Director, Department of Rural Development, Alagappa University, Karaikudi – 630 003 (Tamil Nadu).

The author is thankful to R. Maria Saleth, R.S. Deshpande, S. Neelakantan and C. Ramasamy for their useful comments on the earlier draft of the paper. However, the author alone is responsible for the errors remaining in the paper.

expected to reduce land and water pollution, soil erosion, dependency on external inputs, improve water quality and water use efficiency, environmental management and reduce emissions of green house gases through less use of fossil fuels (www.fao.org). The drip method of irrigation (DMI) too is expected to perform most of these tasks and deliver most of the benefits of conservation agriculture, including environmental benefits. Can DMI be used as tool to achieve the macro objectives of conservation agriculture? Will DMI be used for promoting conservation agriculture in India? In this paper, an attempt is made to study the role of DMI in conservation agriculture by using the farm level data pertaining to four important crops collected from Maharashtra State.

II

CONSERVATION AGRICULTURE AND DRIP METHOD OF IRRIGATION LINKAGES

Before getting into the analysis on the role of DMI in conservation agriculture, let us understand the theoretical relationship between CA and DMI. It is well known that the DMI introduced in India is precisely to conserve water that is used for irrigation. DMI supplies water constantly or at regular intervals at the root zone of the crops through a network of pipes with the help of emitters. Unlike the flood method of irrigation (FMI), the efficiency of water use is extremely high in DMI as it substantially reduces the evaporation, conveyance and distribution losses of water (Narayanamoorthy and Deshpande, 2005; Narayanamoorthy, 1996; 1997, Sivanappan, 1994). The available results in this regard show that the on-farm irrigation efficiency of properly designed and managed drip irrigation system is about 90 per cent, whereas it is about 70 per cent for sprinklers but just about 40 per cent for the surface irrigation method (INCID, 1994; AFC, 1998; Postal, 1999; Dhawan, 2002; Saleth, 2009). Available results from various parts of India indicate that DMI increases crop yield significantly and that too with a reduced cost of cultivation when compared to FMI. The crops cultivated under DMI do not need much ploughing and therefore, it is also well suited for undulating terrain and shallow soils (INCID, 1994).

How is DMI related to conservation agriculture? One of the basic principles of conservation agriculture is to minimise the tillage by plough and hoe so as to reduce soil erosion and improve its health. DMI performs this task exactly. Water is applied only at the root zone of crops (not to the land) under DMI and therefore, it does not warrant much of ploughing which is needed under the conventional flood method of irrigation. This reduces water run-off and prevents soil erosion. The balanced application of precisely the required chemical inputs and careful management of residues is another important objective of CA. The chemical inputs such as fertilisers and other nutrients can be applied in a balanced manner at the required time and quantity for crops under DMI. Fertilisers can be applied along with water (which is known as fertigation) as that increases the efficiency of this input by reducing leaching and evaporation which are common features of the conventional method of irrigation. Reducing emissions of green house gases through less use of fossil fuels is another important objective of CA, which also seems to be possible through the adoption of DMI. DMI saves a substantial amount of water leading to less working hours of pumpsets that ultimately reduces the requirement of fossil fuels. The reduced working hours of pumpsets also appeared to have reduced the requirement of electricity needed for operating the irrigation pumpsets (INCID, 1994; Narayanamoorthy, 2004a). Reducing the cost of cultivation is another macro objective of the conservation agriculture, which is also possible by adopting DMI. It is proved by studies that the cost of cultivation required for performing the operations like ploughing, weeding, irrigation, and labour is considerably lower under DMI as compared to the conventional method of irrigation (INCID, 1994).

Besides, increased adoption of DMI can also generate many environmental benefits. The reduced consumption of water helps reducing the over-exploitation of groundwater, which is a serious problem of the country today. Sea water intrusion and increased chlorine content in groundwater are some of the environmental problems occurring due to over-exploitation of water. Water logging and salinity are the two problems arising mainly because of the practice of conventional flood method of irrigation, which can also be reduced through the adoption of DMI. The top and basal dressing of chemical fertilisers for crops applied predominantly under surface method of irrigation increases the leaching of chemicals to deep aquifers and water bodies. Since the fertilisers can be applied precisely and directly to the plants in controlled quantities using fertiliser dispensers under DMI, the leaching of chemicals to water bodies can be minimised. All these seem to establish that DMI can be used as an effective tool to harvest the benefits of conservation agriculture. Are the farmers adopting DMI able to reduce the tillage of land, conserve the resources and increase productivity of crops? The following section deals with this issue utilising the data pertaining to the four crops collected from the farmers of Maharashtra State.[1]

III

CONSERVATION OF RESOURCES

Augmenting the productivity of crops while conserving the resources needed for the cultivation of crops is one of the basic principles of conservation agriculture. The drip method of irrigation performs exactly this function. In this section, using the author's own empirical studies[2] on four different crops (sugarcane, grapes, banana and cotton) carried out in Maharashtra State, an analysis is presented focusing on the conservation of resources by drip method of irrigation. First, let us study how drip irrigation technology helps conserve water, which is estimated in terms of horse power (HP) hour. It is clear from Table 1 that the consumption of water by crops under drip method of irrigation is significantly less than flood method of irrigation (FMI). While water saving in sugarcane is estimated to be about 44 per cent, the same is estimated to be about 37 per cent in the case of grapes, about 29 per cent in the case of banana and about 45 per cent in the case of cotton crop. Unlike the flood method of irrigation, water is supplied only at the root zone of the crops under DMI and that too at the precisely required quantity and therefore, water losses occurring through evaporation and distribution are completely absent. This helps DMI adopters to conserve an enormous quantity of water as compared to the non-adopters. The requirement of water varies for each crop depending upon the soil quality and other factors and therefore, the saving of water due to DMI also varied among the four crops discussed here.

TABLE 1. CONSERVATION OF RESOURCES BY DRIP METHOD OF IRRIGATION

Parameters (1)	Crops (2)	DMI (3)	FMI (4)	Gains over FMI (per cent) (5)
1. Water consumption (HP hours/ha)	Sugarcane	1767	3179	44.40
	Grapes	3310	5278	37.30
	Banana	7885	11130	29.15
	Cotton	563	1025	45.00
2. Electricity Consumption (kwh/ha)	Sugarcane	1325	2385	44.40
	Grapes	2483	3959	37.30
	Banana	5914	8348	29.15
	Cotton	423	769	45.00
3. Cost of cultivation (Rs/ha)[A]	Sugarcane[B]	41993	48539	13.50
	Grapes	134506	147915	9.00
	Banana	51437	52739	2.50
	Cotton	42989	42467	-1.00
4. Productivity (quintal/ha)	Sugarcane	1384	1124	23.00
	Grapes	243	204	19.00
	Banana	679	526	29.00
	Cotton	45	21	114.70

Sources: Reconstructed from Narayanamoorthy (1997, 2003, 2004b and 2008).
Notes: A - refers to cost A2, except cotton crop, which is cost A2+FL; B - Costs of harvesting and transport are not included in it as sugar factories have already incurred them.

DMI also helps in saving substantial amount of electricity required to lift water from the wells. It is obvious that, along with the reduction in the number of working hours of pumpset use, the consumption of electricity also gets reduced in DMI. It is observed that horse power (HP) hours of water used per hectare of crop under DMI is significantly less than under FMI. Therefore, it follows that the consumption of electricity also gets significantly reduced under DMI.[3] The estimated consumption of electricity (in kwh) clearly depicts that farmers using DMI utilised much less amount of electricity as compared to FMI farmers in all four crops. The farmers who cultivated sugarcane under DMI could save about 1059 kwh of electricity per hectare as compared to farmers who cultivated sugarcane under FMI. Similarly, while the farmers cultivating grapes saved electricity of about 1476 khw/ha due to DMI, the saving of electricity was estimated to be about 2434 kwh/ha in banana over farmers cultivating the same crop under FMI with similar environment. The substantial electricity saving due to DMI is not a surprising result, because any reduction in the consumption of water would ultimately lead to a reduction in the consumption of electricity as well.

The reduced cost of cultivation is an objective of conservation agriculture, which is also possible through the adoption of the drip method of irrigation. Studies carried out using experimental data in different crops indicate that the DMI reduces the cost of cultivation, especially in labour intensive operations like weeding, irrigation, ploughing, etc. (see, INCID, 1994;1998; Dhawan, 2002). When labour cost gets reduced, the total cost of cultivation also reduces because labour cost constitutes a considerable portion of the total cost of cultivation. Table 1 shows that drip irrigation reduces the total cost of cultivation by about Rs.6550/ha (nearly 13 per cent) for the adopters as compared with the non-adopters in sugarcane crop. Farmers cultivating grapes, banana and cotton under DMI have also incurred a relatively lower cost of cultivation. In the case of banana, drip irrigation reduces the total cost of cultivation by about Rs. 1300/ha as compared to farmers cultivating the same crop under flood method of irrigation. Among the different agricultural operations, cost saving is very high in the cost of irrigation. The second highest saving is noticed in the ploughing operation since drip method does not warrant much ploughing as it supplies water at the root zone of the crops. Cost saving in the weeding operation is high when DMI is used because it does not allow weeds to grow in the non-crop space by denying water to all areas beyond the root zone of the crop. It should be underlined here that the reduced cost of the ploughing operation due to the drip method of irrigation is very well augered with the conservation agriculture, which promotes zero tilling cultivation to protect the soil health.

One of the important objectives of drip method of irrigation is to increase the productivity of crops. This is also one of the basic principles of conservation agriculture. Most of the time, yield is affected because of moisture stress faced by the crops. It is difficult to maintain the water supply constantly for crops by surface/conventional method of irrigation due to various reasons. The problem of moisture stress is completely reduced by providing irrigation through drip as it supplies water at the root zone of the crops at a required frequency and quantity. As a result, the yield of crops cultivated under drip method of irrigation is much higher than the crops which are cultivated under the method of surface irrigation. Productivity is significantly higher for the farmers who have adopted the drip method of irrigation as compared to the non-drip adopters in all the four crops. The yield difference between the adopters and the non-adopters of drip method of irrigation comes to about 23 per cent for sugarcane. In the case of grapes, the productivity difference between DMI and FMI adopters comes to about 19 per cent and the same comes to 29 per cent for banana crop. There are three main reasons for higher yield in drip irrigated crops. First, because of less moisture stress, the growth of crops cultivated under DMI is good which ultimately helps to increase the productivity. Second, unlike under surface method of irrigation, drip does not encourage growth of any weeds, especially in the non-crop zone. Weeds consume considerable amount of yield increasing inputs and reduce the yield of crops under surface method of irrigation. Third, unlike the surface method of irrigation, fertiliser losses occurring through evaporation and leaching through water are less under drip method of irrigation, as it supplies water only for crop zone and not for the lands in-between or beyond crop zones. The important point to be underlined here is that despite conserving cost on yield increasing inputs, productivity of crops cultivated under DMI is significantly higher than that of FMI. This is what conservation agriculture precisely promotes.

IV

ECONOMIC VIABILITY

Though DMI conserves water and other resources, one should not come to the conclusion that it can be used as a tool for promoting conservation agriculture. The drip method of irrigation involves fixed investment and therefore, its economic viability needs to be studied clearly using proper methodology before recommending it for CA. A few studies have analysed the impact of drip method of irrigation on different parameters. However, not many studies have attempted to look into the economic viability of drip investment even by using experimental data. Past studies (e.g. INCID, 1994; 1998; Sivanappan, 1994) on the subject have either conducted benefit-cost analysis without a proper methodology or relied heavily on the experience of one or few farmers adopting DMI. There is, therefore, a need to empirically study and evaluate the economic viability of DMI within a relatively more systematic methodological framework. Specifically, we must address the issues of (1) how the factors like fixed investment influence economic viability on DMI, and (2) how government subsidies and farmers' time preference (i.e., the differential discount rates) influence the economic viability of DMI in different crops. We have computed the Benefit-Cost Ratio (BCR) by utilising the discounted cash flow technique to evaluate the economic viability of drip investment in the context of four crops.[4] Generally, if the BCR is more than one, then, the investment on that project can be considered as economically viable (for details see Gittinger, 1984). The BCR can be defined as follows:

$$\text{BCR} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}}$$

Where, B_t = benefit in year t; C_t = cost in year t; t = 1,2,3,…….n; n = project life in years; i = rate of interest (or the assumed opportunity cost of the investment).

Before studying the estimate of the benefit-cost ratio, let us briefly discuss about the cost of production, profit without discount, capital cost (with and without subsidy) so as to understand the relative profit levels of the four crops for the adopters and non-adopters of DMI. Table 2 presents the details of production, gross income and other details for four crops, namely, sugarcane, grapes, banana and cotton. While calculating profit, the total cost was calculated by considering only the variable costs but not the fixed cost components like interest rate and depreciation. We subtract the total cost of cultivation from the total income for the group of adopters and non-adopters so as to calculate per hectare profit. The gross income (in Rs.) is calculated by multiplying the total yield with price received by farmers for their crop output.

TABLE 2. RELATIVE ECONOMICS OF DRIP AND NON-DRIP IRRIGATED CROPS

Parameters (1)	Crops (2)	DMI (3)	FMI (4)	Gains over FMI (per cent) (5)
1. Gross income (Rs./ha)	Sugarcane	106366	85488	24.00
	Grapes	247817	211038	17.00
	Banana	134044	102635	30.20
	Cotton	95558	44151	116.00
2. Farm business income (Rs./ha)	Sugarcane	64373	36948	74.00
	Grapes	113311	63123	44.00
	Banana	82607	50196	64.50
	Cotton	52569	1684	3021.00
3. Capital cost – without subsidy (Rs./ha)	Sugarcane	52811	-	-
	Grapes	32721	-	-
	Banana	33595	-	-
	Cotton	52496	-	-
4. Capital cost – with subsidy (Rs./ha)	Sugarcane	33548	-	-
	Grapes	20101	-	-
	Banana	22236	-	-
	Cotton	26537	-	-

Sources: Reconstructed using Narayanamoorthy (1996; 1997; 2004b and 2008).

The estimates presented in the table show that the per hectare profit[5] of the adopters in sugarcane is Rs. 27424 higher than that of the non-adopters. That is, the profit of the drip adopters is higher by about 74 percent over the profit of the non-drip farmers. This is not surprising because drip irrigation reduces the cost of cultivation of sugarcane and simultaneously increases its yield. The average profit among the drip adopters is significantly higher than that among the non-drip adopters in case of grapes, banana and cotton as well. While the profit differential is substantial for drip irrigated crops, it cannot be taken as a conclusive indicator of the comparative advantages of the new irrigation technique as our profit calculation is based only on the variable cost, but ignores fixed cost components like depreciation and interest accrued on fixed capital while calculating the net profit. The life period of drip-set is one of the important variables which determine the per hectare profit. Moreover, since DMI is a capital-intensive technique, the relatively large initial investment needed for installing drip systems remains as the main deterrent for its widespread adoption. To what extent this deterrent effect is real and to what extent such effect can be counterbalanced by government subsidy are some of the important policy issues requiring solid empirical answers.

Now our focus is on the analysis of the estimates of BCR. Though the farmers (adopters of DMI) in Maharashtra State have received subsidy for installing drip technology for all four crops through government schemes, the BCR has been estimated separately by including and excluding subsidy in the total fixed capital cost of drip set. This is done to assess the potential role that subsidy plays in the adoption of DMI. The BCR is sensitive to the discount rate and the degree of such sensitivity depends on the pattern of cash flows. Therefore, it is interesting to observe the sensitivity of the BCR when there is a simultaneous change in both the subsidy and discount factors. Table 3 presents estimates of B-C ratio for all four crops computed under different scenarios. As expected, the BCR of the investment with subsidy is marginally higher than that under ‘no subsidy’ option in all four crops taken for analysis. In sugarcane, under the without ‘subsidy condition’, the BCR was 1.909 at 15 per cent discount, but it was 2.098 under the ‘subsidy condition’. Similarly, the BCR without subsidy for banana is about 2.253 at 10 per cent discount rate and increases to 2.361 with subsidy. The BCR also increased considerably for both grapes and cotton under subsidy condition as compared to the estimate arrived under the condition of without subsidy. This signifies the positive role that subsidy plays in improving the economic viability of DMI for all the four sample crops irrespective of the time preference of the farmers. One of the important policy issues in the context of DMI adoption is the number of years needed to recover fully the capital costs involved in the drip installation. In order to know this, we have computed year-wise net present value (NPV) for sugarcane, banana, grapes and cotton. The NPV of the first year itself comes to higher than the capital cost of the drip set for all four crops, under subsidy condition. This seems to suggest that the farmers can recover the entire capital cost of the drip-set from their net profit in the very first year itself. This finding is in contradiction to the general belief that the capital cost recovery for drip investment takes more time.

TABLE 3. B-C RATIO OF DRIP IRRIGATED CROPS UNDER DIFFERENT SCENARIOS

Crop (1)	Subsidy Category (2)	Life Period (3)	Discount Rate (per cent) (4)	B-C Ratio (5)
Sugarcane	With subsidy	5 years	15	2.098
		5 years	10	2.289
	Without subsidy	5 years	15	1.909
		5 years	10	2.095
Grapes	With subsidy	10 years	15	1.795
		10 years	10	1.802
	Without subsidy	10 years	15	1.767
		10 years	10	1.778
Banana	With subsidy	5 years	15	2.343
		5 years	10	2.361
	Without subsidy	5 years	15	2.288
		5 years	10	2.253
Cotton	With subsidy	10 years	15	1.956
		10 years	10	1.983
	Without subsidy	10 years	15	1.789
		10 years	10	1.835

Sources: Reconstructed using Narayanamoorthy (1996, 1997; 2004a and 2008).

V

CONCLUSION

An attempt is made in this study to understand whether the drip method of irrigation can be used as an effective tool to achieve the macro objectives of conservation agriculture, which is recently getting popular all over the world. After presenting the theoretical relationship between conservation agriculture and the drip method of irrigation, farm level data pertaining to four different crops collected from Maharashtra State were utilised to find out as to what extent the drip method of irrigation helps to conserve different resources including water used for crop cultivation. The study suggests that the drip method of irrigation can be used as a tool for conserving resources and achieving most of the objectives of conservation agriculture. A significant amount of saving in irrigation water, electricity, cost of cultivation and a substantial increase in the productivity of different crops can be achieved by adopting the drip method of irrigation. Besides, the results of benefit cost analysis suggest that the investment in drip method of irrigation is also economically viable and that too without taking into account government subsidy in four crops, namely, sugarcane, grapes, banana and cotton. In spite of having many advantages for conserving resources, the area under the drip method of irrigation presently occupies only a small portion in the total irrigated area as well as to its total potential area, which is estimated to be about 21 million hectares (Government of India, 2004). Studies relating to Maharashtra State showed that the slow growth of DMI is not mainly due to economic reasons but due to lower degree of awareness among the farmers about the real economic and revenue-related benefits of drip irrigation technology. Given the positive impact of DMI on conserving valuable resources like water, electricity and others, there seems to be a bright chance of achieving the objectives of conservation agriculture by large scale adoption of drip method of irrigation in India.

NOTES

1. Maharashtra is a leading State in terms of the adoption of the drip method of irrigation since the mid-1980s. It accounts for about 50 per cent of India's total drip irrigated area and therefore, Maharashtra is the obvious choice for our study (see, Narayanamoorthy, 2005).

2. The studies on four different crops were carried out at different reference periods and at different locations in Maharashtra. For brevity, we have not presented the details of methodology followed for these studies. The detailed methodology adopted for these studies and the analysis on various issues of drip method of irrigation can be seen in Narayanamoorthy (1997, 2003, 2004b and 2008).

3. The consumption of electricity is estimated based on the hours of pumpset operation for both the drip adopters and the non-drip adopters groups. We have assumed that for every hour of operation of pumpset, 0.750 kwh of power is used per HP to estimate the quantum of electricity saved.

4. The drip method of irrigation involves fixed capital and therefore, it is necessary to take into account the income stream for the whole life span of drip investment. Since it is difficult to generate the cash flows for the entire life span of drip investment in the absence of observed temporal information on benefits and costs, a few realistic assumptions had been made to estimate BCR. These assumptions are: (a) The life period of the drip set is considered as five years for sugarcane and banana, but 10 years for grapes and cotton as followed by the INCID study (1994) as well as the experience gained from the field. (b) The cost of cultivation and income generated using drip method of irrigation is assumed constant during the entire life period of the drip set in all four crops. (c) Differential rates of discount (interest rates) are considered to capture the sensitivity of investment to the change in capital cost. These are assumed at 10 and 15 percent as alternatives representing various opportunity costs of capital. (d) The crop cultivation technology is assumed constant for all four crops during the entire life period of drip set.

5. This profit is calculated by deducting gross income from cost A2 and can appropriately be called as farm business income.

REFERENCES

Agricultural Finance Corporation (AFC) Limited (1998), *Evaluation of Drip Irrigation System*, Mumbai, October.

Dhawan, B. D. (2002), *Technological Change in Indian Irrigated Agriculture: A Study of Water Saving Methods*, Commonwealth Publishers, New Delhi.

Dumanski, J; R. Peiretti; J. R. Benites; D. McGarry and C. Pieri (2006), "The Paradigm of Conservation Agriculture", Proceedings of the World Association of Soil and Water Conservation, Paper No. P1-7, pp. 58-64 (downloaded from www.waswc.org).

FAO (2010), "What is Conservation Agriculture?", (downloaded from www.fao.org, during May 2010).

Garcia-Torres, L; J. Benites; A Martinez-Vilela and A. Holgado-Cabrera (Eds.) (2003), *Conservation Agriculture*, Kluwar Academic Publishers, The Netherlands.

Gittinger J, Price (1984), *Economic Analysis of Agricultural Projects*, Second Edition, The Johns Hopkins University Press, London, U.K.

Government of India (2004), *Report of Task Force on Microirrigation*, (Chairman: N. Chandrababu Naidu), Ministry of Agriculture, January.

INCID (1994), *Drip Irrigation in India*, Indian National Committee on Irrigation and Drainage, New Delhi.

INCID (1998), *Sprinkler Irrigation in India*, Indian National Committee on Irrigation and Drainage, New Delhi.

Narayanamoorthy, A. (1996), *Evaluation of Drip Irrigation System in Maharashtra*, Mimeograph Series No. 42, Agro-Economic Research Centre, Gokhale Institute of Politics and Economics, Pune, Maharashtra.

Narayanamoorthy, A. (1997), "Economic Viability of Drip Irrigation: An Empirical Analysis from Maharashtra", *Indian Journal of Agricultural Economics*, Vol.52, No.4, October-December, pp.728-739.

Narayanamoorthy, A. (2003), "Averting Water Crisis by Drip Method of Irrigation: A Study of Two Water-Intensive Crops", *Indian Journal of Agricultural Economics*, Vol. 58, No. 3, July-September, pp. 427-437.

Narayanamoorthy, A. (2004a), "Drip Irrigation in India: Can it Solve Water Scarcity?", *Water Policy*, Vol. 6, No.2, pp. 117-130.

Narayanamoorthy, A. (2004b), "Impact Assessment of Drip Irrigation in India: The Case of Sugarcane", *Development Policy Review*, Vol. 22, No. 4, pp. 443-462.

Narayanamoorthy, A. (2005), *Efficiency of Irrigation: A Case of Drip Irrigation*, Occasional Paper 45, Department of Economic Analysis and Research, National Bank for Agriculture and Rural Development, Mumbai, India.

Narayanamoorthy, A. and R. S. Deshpande (2005), *Where Water Seeps!: Towards A New Phase in India's Irrigation Reforms*, Academic Foundation, New Delhi.

Narayanamoorthy, A. (2008), "Drip Irrigation and Rainfed Crop Cultivation Nexus: The Case of Cotton Crop, *Indian Journal of Agricultural Economics*, Vol. 63, No. 3, July-September, pp. 487-501.

Postal, S. (1999), *Pillar of Sand: Can the Irrigation Miracle Last?*, W.W. Norton and Company, New York.

Saleth, R.M. (Ed.) (2009), *Promoting Irrigation Demand Management in India: Potentials, Problems and Prospects*, International Water Management Institute, Colombo, Sri Lanka.

Sivanappan, R.K. (1994), "Prospects of Micro Irrigation in India", *Irrigation and Drainage System*, Vol.8, No.1, pp. 49-58.