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Foodgrains Production in India – How Serious is the Shortage of Water Supply for Future Growth?

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ABSTRACT

India has achieved remarkable success in foodgrains production in the last four decades and it has been largely banking on tubewell irrigation. This paper demonstrates theoretically and with the help of econometric results that excess depletion of ground water makes agricultural growth unsustainable in the long-run. Although there is still ground water potential in certain parts of the country and limited scope is also available for utilising surface water, the next frontier of technologies and agricultural research can play the most significant role in this perspective.

Keywords: Ground water, Excess depletion, Unsustainable growth, Surface water, Technology, Agricultural research.

JEL Classification : Q01, Q15, Q25

I

INTRODUCTION

Like many other developing countries India has achieved remarkable success in foodgrains production in the last four decades and it has been done largely banking on ground water extraction. The extension of irrigation has greatly facilitated the use of high-yielding varieties (HYV) seeds and chemical fertilisers leading to significant productivity growth in the farming sector. The net area under cultivation of foodgrains in the country has remained more or less constant at 124 million hectares. But the total production of foodgrains has increased from 108 million tonnes in 1970-71 to 257 million tonnes in 2011-12. The yield per hectare has increased from 872 kilogram in 1970-1971 to 2059 kilogram in 2011-12 (Government of India, 2012-13) and in this growth process, tube-well irrigation has played a crucial role. The net irrigated area in the country has increased from 22.1 per cent of the cultivated land in 1970-1971 to 44 per cent in 2007-2008 and in total net irrigated area, the share of well-irrigation has increased from 12.34 per cent to 60.86 per cent during this period (CMIE, 2010). The huge extraction of ground water has definitely been very helpful for agricultural growth but at the same time it has put a question mark before the sustainability of growth in agriculture in the country (Singh, 2000; Rao, 2002; Singh,

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1992; Sidhu, 2002; Sasmal, 2012a,b). The over-exploitation of ground water has caused salinity and arsenic problems in water, decline in water table in the aquifer and degradation of soil fertility in many parts of the country. The states of Punjab and Haryana where the green revolution technology was most successfully implemented in the 1960s and 1970s, are found to be worst affected by excessive ground water extraction and intensive farming. The study of Bhullar and Sidhu (2006), in the context of Punjab states that the over-exploitation of ground water in the last three decades has played havoc with the resources of the state. The proportion of area where the water table is below the critical depth of 10 meters has increased from 3 per cent in 1973 to 53 per cent in 2000. Rosegrant and Sombilla (1997) warned that the major threat that might come in the way of future foodgrains production would be the shortage of water supply. Ruttan (2002) while explaining the sources and constraints of productivity growth in world agriculture, remarks that water scarcity will be a serious problem in increasing food production in many countries. Tilman *et al*. (2002) while expressing their concern for sustainability of agricultural growth report that roughly 20 per cent of the irrigated area of the United States is supplied by ground water pumped in excess of recharge and overpumping is a serious concern in China, India and Bangladesh also. Now, the question is: how serious is the problem of water shortage for future growth of foodgrains production in India?

In the context of excessive dependence on ground water irrigation, rain water harvesting and crop-diversification in favour of less water intensive crops, watershed development and dryland farming have been suggested as alternative policy options for sustaining growth in agriculture (Shah *et al*., 1995; Rao, 2000, 2002; Ramasamy, 2004; Sasmal, 2006, 2013; Nadkarni, 1993). This paper is basically concerned with the future potential of ground water irrigation for sustainability of growth in agriculture. The growth rate in yield in foodgrains production of India has shown a declining trend in the recent years and here we are trying to investigate whether this declining trend is the outcome of scarcity of water supply. *Ground Water Scenario of India 2009-10*, Ministry of Water Resources, Government of India shows that in certain parts of the country, ground water is over-exploited but in some states there is adequate potential for future growth. On the whole, opportunities left in ground water irrigation are limited and the scope for utilising surface water does not seem to be very high and is conditional on many factors. In this perspective, technological advancement and agricultural research can play a significant role in sustaining growth in foodgrains production by reducing water demand, enhancing productivity of water and ensuring effective management of natural resources. The paper has been arranged as follows : Section II gives an overview of the utilisation of ground water in Indian agriculture and its future potential. In Section III a simple theoretical model has been constructed to demonstrate how excess depletion of ground water can make agricultural growth unsustainable in the long run. In Section IV the theoretical propositions have been empirically verified by econometric analysis based on time series data in the Indian context. Section V explains theoretically the role of technology as policy options for future growth. The summary results and policy implications have been presented in Section VI.

II
UTILISATION AND FUTURE POTENTIAL OF GROUND WATER IRRIGATION IN INDIAN AGRICULTURE – AN OVERVIEW

It is evident from Table 1 that ground water irrigation has played a pivotal role in the foodgrains production of India. The total net irrigated area in the country has increased from 31103 thousand hectares in 1970-71 to 62,286 thousand hectares in 2007-08. It is important to note that the annual average growth rate of area under canal irrigation is only 0.04 per cent during this period and the area under tank water irrigation has declined over this period at an annual average rate of 0.19 per cent. But the area under tubewell irrigation has increased at the rate of 2.56 per cent per year with the result that the share of well-irrigation in total irrigated land has risen to more than 60 per cent in 2007-08 from 38 per cent in 1970-71.

TABLE 1. SOURCES OF IRRIGATION IN INDIA

('000 ha)

Year (1)	Area under canal irrigation (2)	Area under tubewell irrigation (3)	Total net irrigated area (4)
1970-71	12838	4461	31,103
	(41.28)	(14.34)	
2007-08	16531	26105	62,286
	(26.54)	(41.91)	

Source: CMIE (2010).
Figures in parentheses indicate percentage share in total net irrigated land.

Among various food crops rice is a very water-intensive crop followed by wheat and the production of these two crops has significantly increased in the last four decades with expansion of irrigation. It is worth mentioning that production of foodgrains in *kharif* season has increased from 68.9 million tonnes in 1970-71 to 129.9 million tonnes in 2011-12 while in *rabi* season it has increased from 35.9 million tonnes to 127.5 million tonnes in the same period. The implication is that production in *rabi* season could increase significantly due to expansion of irrigation and it has relation with ground water extraction. Furthermore, the elasticity of foodgrains production with respect to irrigation has been found to be 1.18 (the result has been estimated in Section IV). This means, one per cent increase in irrigation has resulted in 1.18 per cent increase in foodgrains production. All these information signify the importance of irrigation in foodgrains production of India. Now, we have to assess whether there is sufficient scope for further expansion of irrigation for future growth of foodgrains production in the country.

Table 2 provides valuable information for our purpose. In most of the major foodgrains producing states like Punjab, Haryana, Uttar Pradesh, Rajasthan, Karnataka and Tamil Nadu ground water extraction is very high and in some cases it has crossed the permissible limits leading to over-exploitation of the resource. However, in the states of eastern India like Bihar, West Bengal, Assam, Jharkhand and Orissa there is still sufficient scope for expansion of ground water irrigation. Table 2 also shows, out of net annual replenishable available ground water of 398.70 billion cubic meters (bcm) of all the states taken together 230.41 bcm is depleted every year (212.37 bcm is used for irrigation and the rest for other purposes) and 161.06 bcm is available for future use. It indicates, 58 per cent of ground water potential is being utilised at present and the remaining 42 per cent is available for future use. But this is not enough for future food security. Hence sincere efforts need to be made for harvesting rain water, crop diversification in favour of less water intensive crops and technological innovations for enhancing efficiency of irrigation systems. Otherwise, the shortage of water supply will be a serious constraint for future growth in agricultural production.

TABLE 2. AVAILABILITY AND UTILISATION OF GROUND WATER RESOURCE IN MAJOR STATES OF INDIA, 2009-10.

(billion cubic metres, bcm)

States (1)	Net annual replenishable ground water availability (2)	Annual ground water draft (including irrigation) (3)	Ground water availability for future irrigation (4)	State of ground water development (per cent) (5)	Per cent of wells showing 10-20 metre water depth below ground level, January 2010 (6)
Andhra Pradesh	32.95	14.90	17.65	45	13.13
Assam	24.89	5.44	19.06	22	2.82
Bihar	27.42	10.77	16.01	39	2.86
Gujarat	15.02	11.49	3.05	76 *	27.76
Haryana	8.63	9.45	– 1.07 **	109 **	30.71
Jharkhand	5.25	1.06	3.99	20	5.14
Karnataka	15.30	10.71	6.48	70 *	14.09
Kerala	6.23	2.92	3.07	47	11.27
Madhya Pradesh	35.33	17.12	17.51	48	22.01
Maharashtra	31.21	15.09	15.10	48	11.29
Orissa	21.01	3.85	16.78	18	1.42
Punjab	21.44	31.16	– 9.89 **	145 **	39.00
Rajasthan	10.38	12.99	– 3.94 **	125 **	29.27
Tamil Nadu	20.76	17.65	3.08	85 *	12.50
Uttar Pradesh	70.18	48.78	19.52	70 *	17.09
West Bengal	27.46	11.65	15.33	42	11.27
Total States	398.70	230.41	161.06	58	--

Source: *Ground Water Scenario of India, 2009-10*, Ministry of Water Resources, Government of India, New Delhi.

*States with high rate of ground water exploitation. **States with over-exploitation of ground water.

Scope for Utilising Surface Water

India experiences huge rainfall every year but only a fraction of it is utilised for irrigation purposes. The total annual precipitation of rain water in India is 37,00,000 million cubic meters (mcm) out of which 17,00,000 mcm flows down the rivers and only 2,67,500 mcm percolates to the ground water aquifer as natural recharge (Government of India, 2009-10). But construction of big dams or river projects like Sardar Sarovar or DVC for utilising this renewable resource is highly debatable and difficult because such projects involve huge environmental and human costs in terms of displacement of people and destruction of forests and ecology. However, the experiences of minor projects are encouraging. The studies by Rao (2000), Chandrakanth *et al*. (2004), Joshi (2006), Shah *et al*. (2009) and Birthal (2013) show that watershed development, rainwater harvesting, technology for dryland farming and artificial recharge to the ground water aquifer can significantly contribute to productivity growth in agriculture. According to the estimates, the increase in yield may range from 12 per cent to 50 per cent. Apart from contributing to productivity growth they are also helpful for conservation of natural resources and the ecology.

III

EXCESS DEPLETION OF GROUND WATER AND UNSUSTAINABLE AGRICULTURAL GROWTH

A Simple Theoretical Model

A theoretical framework has been constructed in the line of Sasmal (2012a,b) to demonstrate that excess depletion of ground water may lead to unsustainability of growth in agriculture. We are considering an agrarian system where production is largely dependent on ground water extraction. A limited amount of surface water may be available for cultivation but its quantity is fixed by the given natural conditions, technology and physical infrastructure. The production function can be specified as

$$Q = F\,(W, Z) \qquad \text{….(1)}$$

where Q is agricultural output, W is extraction of ground water and Z is other input, say, chemical fertiliser. It is assumed that $F_W > 0$, $F_{WW} < 0$, $F_Z > 0$, $F_{ZZ} < 0$. The cost of ground water extraction per unit is C^W and it can be written as a function of stock of ground water (S) and extraction of water (W) i.e., $C^W = C^W$ (S, W) with $C^W_W \rangle 0,\; C^W_{WW} \rangle 0,\; C^W_S \langle 0, C^W_{SS} \langle 0$.

The farmer's income is defined as

$$\pi = P \cdot F\left(\cdot\right) - C^W\left(\cdot\right) \cdot W - P^Z \cdot Z \qquad \text{….(2)}$$

where π is income, P is the price of the crop, and P^Z is the price of Z. P and P_Z are given to the farmer. P may be higher and P_Z may be lower than the free market prices due to price support and input subsidy of the government. The extraction of water causes pollution and environmental degradation but an individual farmer does not take into account the cost of environmental degradation in the decision-making. It may be assumed that there is one cultivator or a group of cultivators in a region who extract water for cultivation. The utility function of the household is

$$U = f(C) \qquad ....(3)$$

where C is consumption and $f'(C) > 0$, $f''(C) < 0$. The consumption depends on income and it may be assumed that the whole income is spent on consumption.

The dynamics of water stock in the aquifer is

$$\dot{S} = -W + R \qquad ....(4)$$

where *R* is natural recharge to the aquifer and it is given by rainfall, natural and geo-physical conditions of the region.

The objective of the farmer is

$$\text{Max} \int_0^{\propto} \pi \cdot e^{-rt} \cdot dt \qquad ....(5)$$

$$\text{s.t.} \quad \dot{S} = -W + R$$

$S(0) = S_0$, $S(T)$ free,

$\text{Lim } T \rightarrow \propto$

where r is the rate of discount of future utility.

It is a dynamic optimisation problem over a planning horizon $[0 \quad \propto]$ that can be solved by optimal control theory as specified in Chiang (1992) and Dorfman (1969).

The current value Hamiltonian of the problem in (5) is

$$H = P \cdot F(\cdot) - C^{W}(\cdot) \cdot W - P_{Z} \cdot Z + \lambda(-W + R) \qquad ....(6)$$

S is state variable and λ is costate variables. λ is actually the present value shadow price of S.

F.O.C.s for maximisation of H are :

$$\frac{\delta H}{\delta W} = P \cdot F_{W} - C^{W} - C_{W}^{W} \cdot W - \lambda = 0 \qquad ....(7)$$

$$\frac{\delta H}{\delta Z} = P \cdot F_Z - P_Z = 0 \qquad \text{….(8)}$$

$$-\frac{\delta H}{\delta S} = \dot{\lambda} = r\lambda + W \cdot C_S^W \qquad \text{….(9)}$$

$$\frac{\delta H}{\delta \lambda} = \dot{S} = -W + R \qquad \text{….(10)}$$

The transversality conditions are:

$$\lambda(T) \geq 0, \; S(T)\lambda(T) = 0$$

$$\lim T \rightarrow \propto$$

S.O.C. is satisfied by the strict concavity of H in W, Z and S jointly (See Appendix). Now, the theorems of Steinberg and Stalford (1973) and Gale and Nikaido (1965) guarantee the globally and uniquely determined optimal values of the control variables in terms of state and costate variables and set of parameters as

$$\hat{W} = \hat{W}\left(S, \lambda, P, P^Z, r\right)$$

$$\hat{Z} = \hat{Z}\left(S, \lambda, P, P^Z, r\right)$$

The marginal condition in equation (7) determines the optimal value of ground water extraction in each point of time by equating the marginal cost of W with its marginal benefit. Here, $\left(C^W + C_W^W \cdot W\right)$ is the direct cost of water extraction and λ is the cost of not preserving the resource for future use. It does not include any environmental or social cost although the extraction of water causes pollution and affects future generations. So, externality problem is there and this may lead to over-exploitation of the resource. The resulting system of equations (9) and (10) will give the optimal paths for S and λ. Since W, Z and Q are linked with these variables in the system, their optimal paths are also obtained from these equations. Therefore, the solution to the problem in equation (5) can be described by the differential equations (9) and (10) along with the transversality conditions. Now, we are interested to see whether the solution to the problem in equation (5) yields a sustainable growth path. For sustainability, we need that water stock remains intact, i.e., $\dot{S} = 0$. That means, the optimal path for extraction of water will be such that the resource base (water stock, S) remains unchanged.

Since the private individuals make under valuation of natural resources, not only λ will be assigned a low value in equation (7) but also this value will decline over time as shown in equation (9). Morever, due to non-inclusion of external cost, price support and input subsidy, the depletion of ground water (W) is likely to exceed its sustainable level and in that case, $\dot{S} \langle 0$ due to excess depletion that means, if W > R, ground water stock will gradually decline making agricultural growth unsustainable in the long run.

Sustainable Balanced Growth in Definite Form

The balanced growth requires that all the relevant variables grow at the same rate. That means, in our case it should be $\psi_Q = \psi_W = \psi_Z$ where ψ_Q, ψ_W and ψ_Z are growth rates of Q, W and Z respectively. Again, the growth is sustainable if $\dot{S} = 0$ implying that W = R. The balanced growth requires that the production function exhibits CRS and the sum of production elasticities of W and Z is equal to unity (Harrington *et al*., 2005). To explain it more precisely let us consider a Cobb-Douglas production function with CRS as follows

$$Q = AW^{\alpha}Z^{1-\alpha} \qquad \text{....(11)}$$

where α and $1 - \alpha$ are production elasticities of *W* and *Z* respectively and *A* is a constant term implying efficiency in production from technology or infrastructure.

Now taking log of (11) and differentiating w.r.t. time we get

$$\psi_Q = \alpha\ \psi_W + (1-\alpha)\ \psi_Z \qquad \text{.... (12)}$$

In equation (12) we find that if *W* and *Z* grow at the same rate, i.e., $g_W = g_Z$, Q will also grow at the same rate. However, given α, if g_W declines g_Q will also decline. The implication is that if there is excess depletion of water, extraction of water (W) will eventually decline and this will lead to decline in the growth rate of production.

IV

ECONOMETRIC RESULTS

This section presents the results of time series econometric analysis based on Indian data and examines the relationship between irrigation, well irrigation, fertiliser use and growth in yield in the foodgrains production of the country. The test of cointegration and regression analyses have been done using annual data on yield per hectare in foodgrains production (YIELD), net area under irrigation (N_IRRI_A) and share of well-irrigation in net irrigated area (W_IRRI_A), tubewell irrigation (T_WELL_IRRI) and fertiliser use (FERT) for 38 years from 1970-1971 to 2007-2008 in the Indian context. The data have been used from *Economic Survey*, Ministry of Finance, Government of India and Centre for Monitoring Indian Economy (CMIE) (various issues). The stationarity of the series of the variables has been checked by Augmented Dicky Fuller (ADF) Unit Root Test. In ADF test, the variables are non-stationary at level but stationary at first difference (see Figure 1 and Table 3). The Engle-Granger Test of cointegration has been done to check the long-run relationship between the variables following the methods explained in Enders (2004).

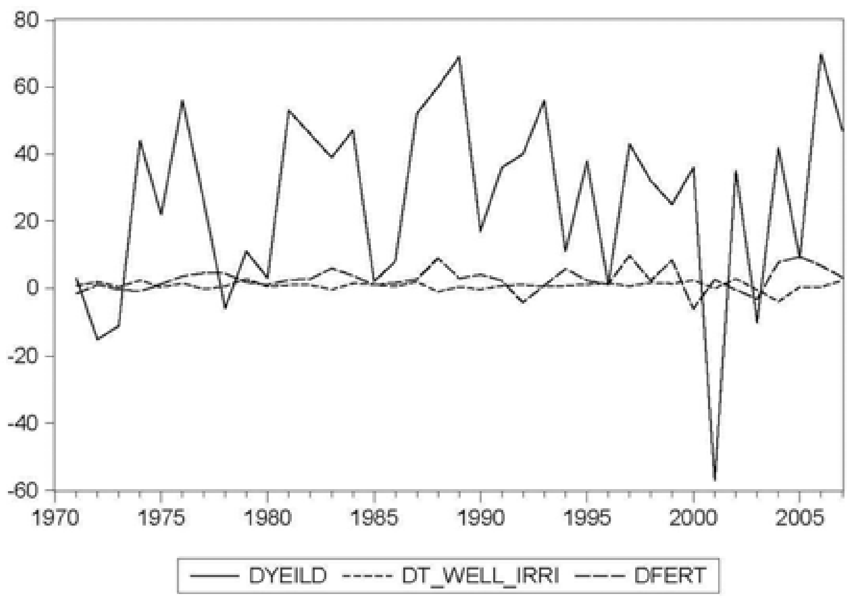

Figure 1. Stationary Series of YIELD, T_WELL_IRRI and FERT at 1st Difference

TABLE 3. AUGMENTED DICKY-FULLER UNIT ROOT TEST ON D (YIELD), D (N_IRRI_A), D (W_IRR_A) AND D (IRRI_CAN) AND STATIONARITY OFTHE SERIES AT 1ST DIFFERENCE

Null Hypothesis : D (YIELD) has a unit root					
				t – statistics **	Prob *
ADF test statistic				– 5.6432	0.000
Null Hypothesis : D (N_IRRI_A) has a unit root					
				t – statistics **	Prob *
ADF test statistic				– 10.0632	0.000
Null Hypothesis : D (W_IRRI_A) has a unit root					
				t – statistics **	Prob *
ADF test statistic				– 9.3058	0.000
**	Test critical values	1 per cent level	– 3.6267		
		5 per cent level	– 2.9458		

*Mackinnon (1996) one sided p – values.

The test of cointegration in Table 4 and 5 show that there is meaningful long-run relationship between yield in foodgrains production and net irrigated area in the country. The results also show that yield, well irrigation and fertiliser use are cointegrated. The coefficients of OLS regression in Table 6 suggest that well-irrigation and fertiliser use have significant positive impact on the growth of yield in foodgrains production in India. And also, well-irrigation has significantly influenced fertiliser use. It is established from the econometric results that ground water extraction has played a crucial role in the productivity growth of foodgrains production of the country.

TABLE 4. RESULTS OF OLS REGRESSION AND TEST OF COINTEGRATION BETWEEN YIELD AND N_IRRI_A

Dependent variable	: YIELD		
Independent variable	: N_IRRI_A		
Variable	Coefficient	*t* – statistic	Prob
N_IRRI_A	0.0329	26.3054 *	0.000
C	– 237.8337	– 3.9889 *	0.000
	R^2 = 0.95	F-statistic = 691.97	
Null Hypothesis : RESI_YIELD_N_IRRI_A has a unit root			
		t – statistic	Prob
	ADF test statistic	– 4.6645 *	0.0006

*Significant at 5 per cent level.

Elasticity of yield with respect to net irrigated area.

Dependent variable	: ln YIELD	
Independent variable	: ln N_IRRI_A	
Variable	Coefficient	*t* – statistic
N_IRRI_A	1.1863 **	26.0898 *
C	– 5.5921	– 11.4595 *
	R^2 = 0.94	F = 680.68

*Significant at 5 per cent level.
** indicates elasticity since ln YIELD is regressed on ln N_IRRI_A.

TABLE 5. ENGLE-GRANGER TEST OF COINTEGRATION BETWEEN (I) YIELD (YIELD) AND WELL-IRRIGATION (W_IRRI), (II) YIELD (YIELD) AND FERTILISER (FERT) AND (III) WELL-IRRIGATION (W_IRRI) AND FERTILISER (FERT)

Null Hypothesis : YIELD and W_IRRI are not cointegrated.				
Dependent	tau – statistics	Prob	z – statistic	Prob
W_IRRI	– 5,.9832	0.0001	– 37.1308 *	0.0000
YIELD	– 5.6262	0.0002	– 34.0684 *	0.0001
Null Hypothesis : YIELD and FERT are not cointegrated.				
Dependent	tau – statistics	Prob	z – statistic	Prob
YIELD	– 6.4609	0.0000	– 39.2466 *	0.0000
FERT	– 6.3190	0.0000	– 37.8394 *	0.0000
Null Hypothesis : W_IRRI and FERT are not cointegrated.				
Dependent	tau – statistics	Prob	z – statistic	Prob
W_IRRI	– 5.9696	0.0001	– 37.1806 *	0.0000
FERT	– 5.4951	0.0004	– 32.7175	0.0003

*Significant at 5 per cent level.

TABLE 6. OLS ESTIMATES OF REGRESSION COEFFICIENTS USING TIME SERIES DATA

Dependent Variable (1)	Explanatory Variable (2)	Coefficient (3)	t-value (4)	R^2 (5)	N (6)
YIELD	T_WELL_IRRI	37.69	22.44*	0.93	38
YIELD	FERT	10.48	41.42*	0.97	38
FERT	T_WELL_IRRI	3.54	21.00*	0.92	38

*Denote significance at 1 per cent level.

In Table 7, we find that the annual growth rate of yield in foodgrains production has declined from 2.77 per cent in the period 1970-1995 to 1.11 per cent in 1995-2007. The annual growth rate of tubewell irrigation has declined from 3.11 per cent in the period 1970-1995 to 1.24 per cent in 1995-2007. Similarly, the growth rate of fertiliser use also has declined from 7.00 per cent to 2.92 per cent over the same period. Here, the empirical evidences and econometric results corroborate the theoretical results in Section III. The declining growth rate in yield in foodgrains production of India has been associated with the declining growth rates of tubewell irrigation and fertiliser use giving an indication that shortage of water supply is becoming a constraint to further growth in foodgrains production of India.

TABLE 7. ANNUAL GROWTH RATES OF T_WELL_IRRI, FERT AND YIELD IN DIFFERENT PERIODS

(per cent)

Variables (1)	Periods 1970 – 2007 (2)	1970 – 1995 (3)	1995 – 2007 (4)
T_WELL_IRRI	2.56	3.11	1.24
FERT	5.59	7.00	2.92
YIELD	2.33	2.77	1.11

V

POLICY OPTION FOR FUTURE GROWTH – TECHNOLOGICAL ADVANCEMENT AND AGRICULTURAL RESEARCH

A Theoretical Exposition

In the backdrop of declining groundwater stock and limited prospect of utilising surface water, appropriate technological advancement and agricultural research can be important policy options for future growth in foodgrain production. Instead of following the traditional path of seeking only supply-side solution to the problem of water shortage, the next frontier of technological progress and agricultural innovations can be applied in agriculture to reduce the demand for water in cultivation, increase overall productivity in the farming sector, reduce water losses in irrigation, enhance productivity of water and protect the resource base in agricultural production. Birthal (2013) summarises the significant positive contributions of irrigation technology, biotechnology and information technology to agricultural productivity. The study empirically shows that improved irrigation technology can save 20-35 per cent water and biotechnology has enough potential for productivity growth in agriculture. However, such technological progress has to come in as public good and for that matter, the government will have to make sufficient public sector investment on agricultural research. Again, the research has to be region-specific and crop-specific. Dev (2012), however, reports that the rate of public investment in Indian agriculture was negative during the period from 1981 to 2000 although it has become positive in the period from 2001 to 2009.

The improved irrigation technology can help agricultural growth by increasing productivity of water in cultivation. To demonstrate it theoretically let us now modify the production function in (11) as

$$Q = A\left[e(T)\cdot W\right]^{\alpha} Z^{1-\alpha} \qquad \text{....(14)}$$

where *e* is efficiency of water generated by improved irrigation technology T and $e'(T) \rangle 0$. It may be assumed that

$$e = T^{\beta} W^{1-\beta} \qquad \text{....(15)}$$

Here, efficiency of water from irrigation technology is a substitute of water supply.

Then (14) can be written as

$$Q = A\left\{T^{\beta}\cdot W^{1-\beta}\right\}^{\alpha} Z^{1-\alpha} \qquad \text{....(16)}$$

Now taking log of (16) and differentiating w.r.t. time we get

$$g_Q = g_A + \alpha\beta\, g_T + \alpha(1-\beta)\, g_W + (1-\alpha)\, g_Z \qquad \text{....(17)}$$

where g is growth rate of i-th variable,

i = Q, A, T, W, Z

If availability of water remain constant, $g_W = 0$. If technological progress takes place in agriculture and in the irrigation system, then we get

$$g_Q = g_A + \alpha\beta\, g_T + (1-\alpha)\, g_Z \qquad \text{....(18)}$$

If efficiency of water from technology (*T*) is high, value of β will be also high. Then agricultural production can grow at a high rate without increase in water supply. Therefore, if agricultural technology and irrigation system can be improved sufficiently shortage of water may not be a constraint to future growth in foodgrains production.

VI

SUMMARY RESULTS AND POLICY IMPLICATIONS

This paper reviews the role of irrigation in foodgrains production of India and examines its potential for future growth in the country. It establishes that irrigation, particularly ground water extraction, has played a crucial role in the growth of yield in foodgrains production in the last four decades. The study shows theoretically and with the help of econometric results that the declining rate of growth of yield in foodgrain production has been associated with declining rate of increase of ground water irrigation. It is observed that in certain parts of the country, specially in the eastern states, there is some scope for increasing ground water irrigation but in other states like Punjab, Haryana, Rajasthan, Uttar Pradesh, Gujarat, Karnataka and Tamil Nadu, depletion of ground water is very high and in some cases it has crossed the sustainable limits. Although surface water has remained largely under-utilised, it can not be increased to any significant extent for various reasons. No doubt, the shortage of water supply is going to be a serious constraint to future growth in foodgrains production of India. In this perspective rain water harvesting, watershed development, crop-diversification in favour of less water-intensive crops and dryland farming may be helpful to some extent for agricultural growth. But the next frontier of technological advances and agricultural research can play a significant role in future growth of agriculture by way of reducing water demand and enhancing the productivity of water in cultivation.

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APPENDIX

Differentiation of (7) – (9) in Section III w.r.t. W, Z and S gives

$$\begin{bmatrix} P.F_{WW} - C_W^W - W \cdot C_{WW}^W & 0 & -C_S^W \\ P.F_{ZW} & P.F_{ZZ} & 0 \\ C_S^W & 0 & W \cdot C_{SS}^W \end{bmatrix}$$

$| D_1 | < 0,\ | D_2 | > 0,\ | D_3 | < 0.$