AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION	A. PRIMARY Agriculture	AP12-0000-G635
	B. SECONDARY Drainage and irrigation--India	

2. TITLE AND SUBTITLE
A comparative study of well irrigation in Aligarh District,India

3. AUTHOR(S)
Moorti,T.V.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1971	66p.	ARC IN631.7.M825

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Cornell

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*
(In Cornell int.agr.development bul.,19)

9. ABSTRACT

10. CONTROL NUMBER
PN-RAA-295

11. PRICE OF DOCUMENT

12. DESCRIPTORS
India
Water wells
Benefit cost analysis
Uttar Pradesh?

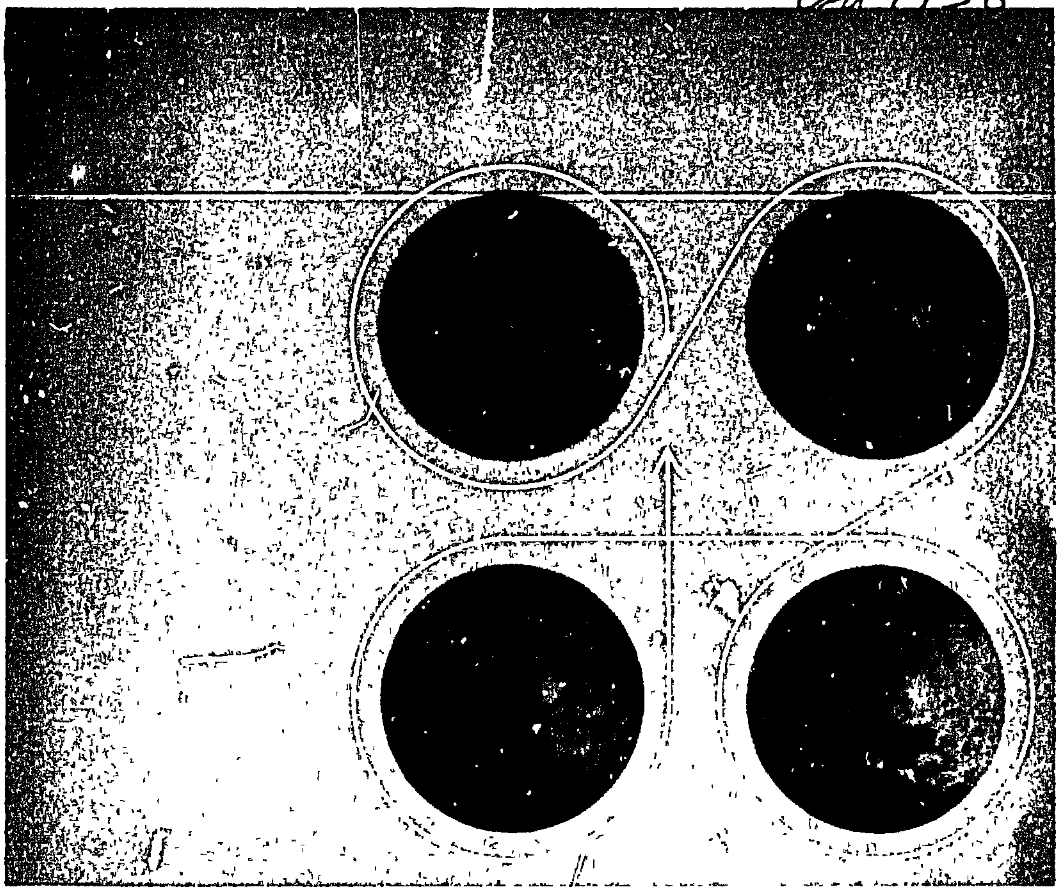
13. PROJECT NUMBER

14. CONTRACT NUMBER
CSD-1438 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

CORNELL INTERNATIONAL AGRICULTURAL DEVELOPMENT BULLETIN 19



A COMPARATIVE STUDY OF WELL IRRIGATION IN ALIGARH DISTRICT, INDIA

T. V. MOORTI

A Joint Project of
The Agricultural Experiment Station of the
Uttar Pradesh Agricultural University and the
Department of Agricultural Economics of
Cornell University

NEW YORK STATE COLLEGE OF AGRICULTURE
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May 1971

Acknowledgments

Dr. John W. Mellor, whom I first met during his visit to India in 1959, is one of my sincere friends and most respected teachers. Over the years I have derived immense inspiration from him in the field of agricultural economics. His encouragement, inspiration, and efforts made it possible for me to be at Cornell University for the period 1965-66. He was also instrumental in obtaining the financial help from the Agency for International Development that enabled me to undertake this project. Dr. Mellor then encouraged me to start this project at Aligarh, India, during 1966-67, and helped me from beginning to end.

I am deeply grateful to the Agricultural Development Council, New York City, which provided a fellowship enabling me to receive advanced training in a stimulating academic environment at Cornell.

I am also indebted to Dean N. K. Anant Rao of the U.P. Agricultural University, Pantnagar, who gave me so much encouragement and generously permitted me to extend my study leave as long as necessary to complete this project.

Further gratitude is extended to Dr. Roshan Singh, R.B.S. College, Bichpuri, Agra, and to Dr. K. Kanungo, Dean and Joint Director, I.A.R.I., New Delhi, former heads of the Department of Agricultural Economics at U.P.A.U., Pantnagar. Their suggestions at various stages of the project were extremely helpful. Also, my thanks to Mr. K. S. Krishnan, Senior Statistician, I.A.R.S., New Delhi, who assisted me in the programming, coding, and analytical work; also to the authorities at I.A.D.P. and to the State Tube Well Department at Aligarh, for providing me with the necessary data.

Additional thanks go to colleagues and friends at Pantnagar and elsewhere who gave me valuable suggestions from time to time: Professor Jaswant Singh, Dr. Ambika Singh, Dr. A. S. Sirohi, Dr. Raghubar Singh, Dr. D. K. Desai, Mr. J. S. Saxena, Mr. Harpal Singh, Dr. Robert W. Herdt, and others.

I also wish to acknowledge the assistance of a number of investigators who collected and processed data and to the people at Cornell University who arranged for publishing the manuscript.

Finally I am thankful to my wife, Indira, who often extended her helping hand during the preparation of the manuscript and also for her patience in suffering through its long preparation.

Contents

Preface

One of the major influences of the new high-yielding crop varieties in India has been to greatly increase the returns to irrigation. This development has lent urgency to studies of the economics of irrigation. We need information concerning the physical response to irrigation under varying conditions of farming. We need to know the costs and returns from using different sources of water, and the factors related to these sources which may influence their effect on the level of crop production. We particularly need to know in detail the nature of the interactions between water and new crop varieties. With this information, sound policy can be developed for expanding irrigation resources and for taking full advantage of the potentials of the new crop varieties.

This research is a detailed study of the economics of well irrigation in western Uttar Pradesh, India. The author conducted a substantial field survey in Aligarh District, which in its first stage continued for over a year and later involved a series of small follow-up surveys. He collected detailed physical input–output data from a sample of farmers. These data deal with the full range of inputs used in crop production and the result in outputs. Data were collected on a plot-by-plot basis, thereby providing a large number of observations for analysis of functional relationships. The extraordinarily large amount of data collected required much time in checking and processing for analysis. The author also collected data in detail on the costs of various sources of irrigation, the practices which accompanied them, and the result in crop combinations and yield. Of particular interest is his analysis of the costs, returns, and operating procedures for state and privately operated tube wells.

This research provides a basis for later studies of the effects of new technologies and new price relationships on cropping combinations and acceptance of new farming practices.

T. V. Moorti's study was a joint research project of the U.P. Agricultural University and the USAID Prices Research Project at Cornell University. We are grateful for the financial and other assistance provided by the Rural Community Development Division of USAID and in particular to Douglas Caton, Norman Ward, and Voyce Mack of that division. As director of the Cornell University Prices Research Contract, I wish to express my particular appreciation for the opportunity to be associated with this project at the U.P. Agricultural University. The knowledge contributed by several persons in various departments at the U.P. Agricultural University was obviously crucial to the success of a project as involved as this one.

The broad program of study under the Cornell University Prices Research Contract, of which this work is a part, covers 3 major areas of inquiry: the role of prices in intersectoral income and capital transfers; the effect of price relationships on agricultural production and marketings; and the factors affecting urban prices of agricultural commodities. These studies are concerned with the effects of agricultural prices on the nonagricultural sectors of the economy, with their effects in the agricultural sector, and with the manner in which agricultural prices are determined. Over the course of the contract a substantial number of studies will be carried on in several countries dealing with various aspects of the processes. At the completion of these studies, an effort will be made to pull them together into an integrated view of the role and functioning of agricultural prices in the developmental process.

John W. Mellor

Chapter 1

Introduction

The introduction of new technology to Indian agriculture has resulted in the increased use of fertilizer and water. Traditional methods of irrigation employing the Persian wheel and *charsa* cannot supply enough water at low enough cost for high-yielding varieties of staple crops. Tube wells can meet this demand. Commencing in about 1930, Uttar Pradesh was the first state to launch a tube well program. The primary objective of the early tube well programs was to protect cultivators from drought. Today the importance of tube wells has significantly increased and they have helped to greatly increase intensity of farming.

State tube well operations are criticized for failing to fulfill farmers' demand for water, high revenue losses to the state, and malpractices in management. Private tube wells, managed by cultivators, are springing up rapidly, sometimes in competition with the state tube wells. Examinations of this competition enables us to answer several questions about the economics of state and private tube wells, such as the optimal allocation of water to crops, returns to water from the 2 kinds of wells, and state tube well pricing policy for water.

The major objectives of this study are: (1) to estimate returns to water use at different levels of application and under varying farm operating conditions; (2) to analyze the differences in cropping patterns, yields, and levels of technology accompanying different systems of well irrigation; and (3) to compare costs and net returns to different systems of well irrigation. The objectives are met by an analysis of detailed farm survey data from 141 farms representing 4 irrigation techniques. The data are for the year 1966–67. Different sources of irrigation were studied to provide a wide range of costs of water use and to facilitate study of the effect of water cost on water use practices and returns.

Location of Study

The study was undertaken in Aligarh District, Uttar Pradesh. Aligarh District is in the Intensive Agricultural District Program (IADP), which provides special access to improved technology. Cooperatives and other loaning agencies, such as land mortgage banks, function well in the district. Aligarh has a wide range of facilities for irrigation, including active programs for development of private and state tube wells. Aligarh District produces a wide range of crops and is not dominated by sugar cane, as are some other districts of Western Uttar Pradesh which have widespread irrigation systems.

Sampling Procedure

Clusters of villages beyond a 5-mile radius of the town of Aligarh, predominately irrigated by state tube wells, Persian wheels and charsa, were purposely selected for study. Another cluster 20 miles from Aligarh was chosen as an area irrigated by private tube wells. Farms entirely irrigated from the same source were listed with the help of extension agency workers and the village *pradhan* (leader). The farms listed were categorized by size and irrigation source and farmers were randomly selected from these specified categories. Table 1 gives the proportion of the sample area to the area selected for survey by source of irrigation.

A preliminary survey of farms in Aligarh District revealed that about 50 percent of the holdings ranged from 1 to 3 hectares, and another 30 percent were between 3 and 8 hectares in size. Farmers were selected from these 2 major size groups. In addition, a third category of large farms with private tube wells was selected. These farms range from about 8 to 17 hectares in size and represent about 5 percent of the farm population. The number of farms in each size group and the source of irrigation selected is indicated in table 2. The average size of holding is similar for each source of irrigation within each size group (table 3). There were 27 private tube wells, 44 Persian wheels, 14 charsas, and 9 state tube wells from which the farmers in the sample irrigated their fields. More than one farmer irrigated from many of the wells.

Small farmers rent land in order to make a viable economic unit for using a pair of bullocks. In this sample, small farmers increased their size of operating unit nearly 30 percent by renting land (table 4). Rental is most often on a yearly basis and is usually extended. Typically, the small farms in the sample had much less acreage per permanent farm worker than the larger farms had (table 5). This was most marked for the farms with more intensive irrigation systems.

Table 1. **Area irrigated by source and sampling percentage (Survey of 141 farms, 1966–67)**

Source of irrigation	Area irrigated, by source, in cluster from which sample was taken	Area surveyed	Percent sampled
	hectares		percent
State tube well	390	130	33
Private tube well	700	310	45
Persian wheel	210	140	70
Charsa	120	60	50

Table 2. **Size of farm and sources of irrigation**
(Sample of 141 farms, 1966–67)

Class (range of area in hectares)	Average hectares	Number of farms with:				
		State tube well	Private tube well	Persian wheel	Charsa	Total
Small (0.72–3.0)	2.28	20	16	21	6	63
Medium (3.3–7.8)	5.17	16	18	20	8	62
Large (8.4–17.4)	11.53	–	16	–	–	16
Total	4.5	36	50	41	14	141

Note: 2.47 acres equals 1 hectare.

Table 3. **Average size of holding by source of irrigation**
(141 farms, 1966–67)

Farm size	Class interval	State tube well	Private tube well	Persian wheel	Charsa	Average
			hectares			
Small	0.5 to 3.0	2.3	2.1	2.3	2.4	2.2
Medium	3.1 to 8.0	5.5	5.2	4.8	5.2	5.1
Large	8.1 to 18.0	–	11.5	–	–	11.5
Average		3.9	3.8*	3.5	4.0	3.7†

*Average for small and medium farms; when large farms are included, average size of private tube well farms is 6.3 hectares.

†Average for small and medium farms; when large farms are included, average size of holding is 4.6 hectares.

Measurement of Water Delivery

Study of costs and returns from water use require careful measurement of water delivery from sources to fields. Delivery capacity was measured at the spot for each source of irrigation by a V-notch suitable to the size of water discharge. Various sources of error in calibration and measurement could be as much as 5 to 10 percent. When a charsa was used the flow of water was not continuous; it was measured by counting the number of lifts per hour, volume of water in a bucket, and spillage waste. By multiplying the delivery rates by the number of hours irrigated, volume of gross water delivered to each field was calculated. For state tube wells, official records of the volume of water delivered to cultivators' fields were collected from government offices. Estimates for all other inputs and outputs were made from survey data collected by interview of farmers.

Table 4. **Areas owned and operated, by farm size groups and source of irrigation**
(141 farms, 1966–67)

Farm size	State tube well		Private tube well		Persian wheel		Charsa		Total	
	Owned	Operated	Owned	Operated	Owned	Operated	Owned	Operated	Owned	Operated
	hectares									
Small........	46	62	34	41	48	59	15	22	143	184
Medium......	88	89	94	96	97	95	42	44	321	324
Large........	–	–	185	164	–	–	–	–	185	164
Total......	134	151	313	301	145	154	57	66	649	672

Table 5. **Area operated per permanent farm worker**
(141 farms, 1966–67)

Farm size	State tube well	Private tube well	Persian wheel	Charsa	Average
			hectares		
Small	1.5	1.2	1.8	1.8	1.5
Medium	2.8	2.0	2.1	2.3	2.3
Large	–	3.5	–	–	3.5
Average	2.1	1.7*	2.0	2.1	1.9†

*Average for small and medium farms only; when large farms are included, average is 2.3.

†Average for small and medium farms only; when large farms are included, average is 2.2.

Table 6. **Wholesale prices of selected commodities for calculation of gross revenue in the study**
(Rs. per quintal)

Commodities	Estimated price in 1964–65 (from regression analysis*)	Percentage deviation from price of desi wheat (+) or (–)	Price derived for use in 1966/67
Bajra	41.58	– 5.00	56.00
Maize	32.00	– 27.00	51.00
Jowar	38.03	– 13.00	49.00
Cotton, American	125.74	+186.00	200.00
Cotton, desi	N.A.‡	N.A.	160.00
Urd (whole)	99.26	+127.00	133.00
Wheat, desi	43.79	–	70.00
Wheat, Mexican	N.A.	N.A.	63.00
Barley	31.70	– 27.00	51.00
Pea	N.A.	N.A.	63.00
Gram	42.33	– 3.00	68.00
Barley + pea	N.A.	N.A.	57.00
Barley + gram	N.A.	N.A.	57.00
Arhar (dal)†	68.83	+ 57.00	110.00
Gur	56.92	+ 30.00	91.00
Potatoes	24.50	– 45.00	39.00
Mustard (laha)	93.52	+114.00	150.00

*Volume for 1964–65 read off 1954–55 to 1964–65 trend line.

†20 percent discount to be given for Arhar whole.

‡N.A. = not available.

Derivation of Prices

Calculations of returns to water use require the employment of a set of crop prices. For this study prices were derived by: (1) fitting a trend line to harvest season wholesale price data for principal markets in Uttar Pradesh, as reported by the Directorate of Economics and Statistics, Ministry of Food and Agriculture, for the period 1951–55 to 1964–65; (2) reading from this trend line a price for 1961–65; (3) calculating the percentage deviation of the price of each commodity from the price of desi wheat for 1961–65; (4) arbitrarily setting the price for desi wheat in 1966–67 at Rs. 70 per quintal, and adjusting the other prices to this by using the percentage deviation calculated in step 3. These data are shown in table 6.

Chapter 2

Operation, Performance, and Costs of Well Irrigation

Description of Irrigation Sources

State tube wells

State tube wells are under direct administrative control of the State Tube Well Directorate of the Irrigation Department. Before 1966–67, 430 wells were sunk in Aligarh. Most of the wells are strainer types with a 6-inch delivery pipe and vertical pump. Most wells are located at a high elevation to facilitate the flow of water in all directions. The usual design is a pump house with concrete tanks and *pucca guls* (lined canals), each up to a mile long. Maintenance of *Kaccha guls* (unlined canals) is the responsibility of the cultivators.

An operator is in charge of each well; a village headman called a *Kuprashak* (well keeper) is designated in the village where the well is situated and receives an honorarium of Rs. 20 per month. Approach roads for each well are maintained for the repair and supervisory staff.

Water is distributed according to the *Thokbandi* (rotational system). This means that at the advice of the *Pradhan* and the cultivators the whole village is divided into several *thoks* (sectors). Each cultivator gets his water in turn, either during the day or night. If the power fails during the turn of a particular farmer, he loses that turn. Operators keep a record of water readings for the individual irrigated fields and the cultivator is accordingly billed. The *amin*, an official of the Tube Well Department, collects the water charges.

Private tube wells

In this sample all private tube wells are electrically driven. An electrical connection for a private tube well within a 600-meter radius of a state tube well can be obtained with a no-objection certificate from the Tube Well Department. This certificate is granted on the following grounds: a) water does not reach the applicant's field; b) the applicant's field is not within the command area of the state tube well. No-objection certificates are not required to install a tube well beyond the specified radius of a state tube well. A private tube well owner cannot sell water within the command area of the state tube well, regardless of whether the state tube well can supply needed water.

Most of the private tube wells are a cavity type with a delivery pipe of 3 inches, a suction pipe of 4 inches, and a centrifugal pump. Boring is usually done by a staff of the Extension Block, which charges a nominal rate of Rs. 150 per boring. Most of the engines in the sample study are either 5 or 7½ horsepower.

Rules and regulations regarding the priority for electrical connections change from year to year. The 1968–69 rule was that the farmer who deposited the full amount for the installation of electric poles from the nearest available power line to the point of electrical connection was given priority. The connecting fee of motor horsepower is compensated for through lower electricity rates for the investor. Loans for up to half of the investment on a 6¼ percent interest rate are available from the extension office.

Persian wheels

The equipment for a Persian wheel consists of 25 to 30 buckets, each with a 6- to 8-liter capacity, which move on a chain, lifting water and emptying it into a trough from which it flows to the fields. The wheel revolves by means of a gear system which is attached to a shaft rotated by a pair of bullocks or a camel. Since the number of buckets increases with the depth of the well, the bullocks cannot operate a system which is deeper than about 27 feet (9 meters). There is a constant flow of water from the well when the equipment is working.

Charsa

A charsa consists of a leather bucket of usually 80- to 100-liter capacity pulled by a pair of bullocks which, at the time of lifting, walk down a steep incline cut to facilitate the draft. One man works the bucket, spilling the water when it comes to the surface; another man drives the bullocks. Usually, some feed or fodder is kept near the well to entice the bullocks into a quick return from downhill. Thus, the bullocks get a small rest after their return to the top of the hill — unlike the Persian wheel system where they must keep revolving.

Table 7. **Comparison of performance of different irrigation sources**
(141 farms, 1966–67)

Item	Units	State tube well	Private tube well	Persian wheel	Charsa
Depth of the well	meters	60	20	7	9
Delivery capacity per hour*	cu. meters	145	68	12	8
Running hours per year (approximately)	hours	4,000	1,500	800	1,100
Water delivered per year	in 100 cu. meters	5,650	1,030	97	86
Area irrigated per well	hectares	.35	20	3.5	3.5
Depreciation rate assumed for equipment	percent	5	10	15	50
Proportion of fixed costs to total costs	percent	57	43	41	20

Note: 100 cu. meters/hour approximately equal to 1 acre inch, or 1 cusec.

*Measurement techniques may have overstated discharge rates for Persian wheel and private tube wells by 5 to 10 percent.

Farmers generally shift from a charsa system to a Persian wheel system as farm income rises, provided the well is not too deep for the bullocks to pull the buckets. In the survey area the wells are often too deep for the Persian wheel operations, so few Persian wheels are found.

Performance of Irrigation Sources

Table 7 gives information about the performance of different types of wells. The delivery capacity of a state tube well is about twice that of a private tube well and it pumps from a depth 3 times that of a private tube well. Traditional equipment such as Persian wheels and charsa are installed in shallow wells only 7 to 8 meters deep and with a very low discharge rate.

The command area defined for the state tube wells covers about 300 hectares or 750 acres. This area is redefined from year to year and is gradually being reduced. The 10 state tube wells in the sample irrigated an average area of 135 hectares per well in the rabi season. Farmers' estimates of the area irrigated per private tube well are about 20 hectares or 50 acres. For Persian wheel and charsa systems, the area irrigated per well is about 3½ hectares.

The average state well is run 4,000 hours per year as compared to 1,500 hours for a private tube well with twice the delivery capacity of private wells. State wells operate 2⅔ times as many hours, pump 5½ times as much water, and irrigate 7 times the acreage. On this basis, they appear more efficient. Later chapters will discuss the problems of uncertain supply, which reduce the returns to state tube well water.

There is a discrepancy between the volume of water pumped from the state tube wells according to official records and according to the survey records. Survey farms included 10 percent of the acreage irrigated from the 10 wells in the sample. The volume of water estimated for these farms from the survey records was equal to 10 percent of all the water pumped from these wells, while the volume shown on the official records came to 7 percent. This information indicates that the records of per farm delivery may understate the amount by about 25 percent.

Monthly use of water on sample farms during 1966–67

Table 8 gives average volume of water per hectare used by farms employing various sources of water for irrigation. The study shows that private tube well farms used the largest quantity of water. This is probably due to a combination of lower cost and better water control in terms of availability and timeliness of application. Farms irrigated by private tube wells use relatively more water for rabi season irrigation, reflecting the relatively large acreage of dwarf wheat. Charsa irrigated farms used the least quantity of water per hectare. The quantity of water used per hectare is similar for state tube wells and Persian wheel systems.

Table 8. **Monthly average delivery of water per hectare under different sources of irrigation**
(141 farms, 1966–67)

Month and year	State tube well	Private tube well	Persian wheel	Charsa	Average
	Cubic meters per hectare				
May 1966	100	150	120	10	110
June 1966	370	310	120	80	250
July 1966	240	220	100	60	170
Aug. 1966	240	280	100	80	200
Sept. 1966	340	390	150	50	270
Oct. 1966	550	620	390	260	500
Nov. 1966	220	390	240	160	280
Dec. 1966	500	840	510	370	610
Jan. 1967	530	880	570	420	660
Feb. 1967	510	730	480	350	560
March 1967	240	470	290	140	320
April 1967	30	70	–	10	40
Total	3,870	5,350	3,070	1,990	3,970

A relatively high volume used in October by private tube well farms (620 cubic meters per hectare) can be attributed to requirements of *palewa* (pre-sowing) irrigation, which is necessary for the preparation of fields after *kharif* harvest, for sowing wheat, or any other rabi crop. Very little water is used in April, the peak month for wheat harvest and thrashing.

Cost of Water from Different Sources of Irrigation

A summary of costs for each type of well has been given in table 9. A breakdown of costs is given in appendix tables 1, 2, 3, and 4. In calculating costs for state and private tube wells, care has been taken to keep the components uniform for comparison purposes. The costs of transmission of electricity to the well have been excluded in both cases. The land costs also have been excluded for both types of well. For private tube wells, the water delivered was calculated from monthly electric bills by converting the electrical units consumed. Care has been taken to apportion the use of power for purposes other than use by tube wells.

Table 9 illustrates that there is extensive investment in state tube wells. The initial investment, besides transmission and land, is about 15 times the investment for a private tube well, despite the fact that delivery capacity of state tube wells is only twice that of private tube wells. Equipment and civil works account for equal proportions in total investment in state tube wells; equipment accounts for nearly 60 percent and civil works 40 percent of the investment in private tube wells.

Table 9. **Comparison of various components of costs for different sources of irrigation (141 farms, 1966–67)**

Items	State tube well	Private tube well	Persian wheel	Charsa
	rupees			
Initial investment:				
Equipment...	38,300	3,000	600	115
Civil works...	38,200	2,100	1,200	1,200
Total...	76,500	5,100	1,800	1,315
Annual costs:				
Fixed costs...	10,711	1,010	294	213
Variable costs...	7,980	1,272	433	820
Total...	18,691	2,282	727	1,033
Cost of water per 1,000 m³...	33	22	75	120

Note: See appendix tables for detailed breakdown of costs.

State tube wells are deeper than private tube wells, making them less vulnerable to the effects of a declining water table. This may eventually be an advantage, although at present it does not result in lower costs.

The proportion of fixed costs to total costs are very high for state tube wells, accounting for much of the high cost of water. The proportion of variable costs of operating the Persian wheel and charsa are high, due to charges for bullocks and human labor. Since 2 laborers are needed to draw water for the charsa system, about 60 percent of the total cost is for wages.

Maintenance and repair expenses are also significant in making state tube well water expensive. The average maintenance and repairs per state tube well come to nearly Rs. 4,000, which is about half the variable costs, as compared with only Rs. 250 per private tube well, which is about 20 percent of the variable costs. In spite of the high maintenance expenses, repair of state tube wells is not done quickly, adding to the uncertainty of water supply.

Costs were calculated on the basis of the water delivered during 1966–67. It is evident that water from private tube wells is the cheapest, at Rs. 22 for 1,000 cubic meters at the source. Water from state tube wells is 1½ times costlier. If tips to state tube well operators are included, the water from this source is nearly twice as expensive as from private tube wells. Water from a charsa system is the costliest of all sources and is about 1½ times costlier than water from a Persian wheel system (Rs. 75 per 1,000 cubic meters). It is the nearly fourfold difference in cost of water that explains much of the great variance in farming intensity, gross production, and net income between the farms irrigated from private tube wells and those irrigated by charsa systems. With much cheaper water available, farms irrigated from private tube wells use it in greater quantity, combine more of other inputs with it, and obtain much higher yields.

The state tube well department charges only Rs. 14 per 1,000 cubic meters (@ 16,000 imperial gallons per rupee) according to the old tariff system, but the charges run around Rs. 18 per 1,000 cubic meters according to a new partially enforced tariff system. Payment of tips to the well operator is common and approximates an additional Rs. 6 per 1,000 cubic meters for a total cost to the farmer of Rs. 20 to Rs. 24.[1] If cultivators are charged for 25 percent less water than received, as discrepancies in the records seem to show, the net to the cultivator is reduced to Rs. 14 or 16 per 1,000 cubic meters. The private tube well owners sell water at the rate of Rs. 2 per hour, and have an average discharge rate of 68 cubic meters per hour, or about Rs. 30 per 1,000 cubic meters of water.

While the cost of state tube well water is 1½ to 2 times the cost of private tube well water, the state tube well water is priced at 30 percent or more lower than private tube well water. State tube well water is heavily subsidized, while private tube wells show a profit without subsidizing. Nevertheless, cultivators prefer to buy private tube well water, even at a higher price, because operation at a lower percent of capacity and more careful management tend to maintain a more reliable supply. If the state tube wells tried to achieve greater certainty and flexibility of supply to farmers by pumping fewer hours, the high fixed costs would make the costs per unit soar. It is the extremely high capital costs of state tube wells that make them basically noncompetitive with private tube wells.

Operational Features of Private Tube Wells

Although the private tube wells averaged a delivery capacity of 68 cubic meters per hour, 2 of the 27 wells averaged only 32 cubic meters per hour, and 3 averaged 112 cubic meters per hour. Only 2 of the wells were deeper than 100 feet, while 6 were between 45 and 60 feet.

Nearly 70 percent of the total investment in private tube wells was financed by farmers and about 20 percent was borrowed from money-

[1] The operator of the state tube well is usually tipped; the amount of this tip *(bakshish)* is from Rs. 3 to Rs. 12 per hectare, per irrigation, depending on demand for water, existence of alternative source of irrigation, and availability of water from private tube wells. More private tube wells in the command area of a state tube well mean lower rates of this *bakshish* to the operator. Some farmers tip the operators periodically in wheat, green fodder, or *bhusa* after the usual harvests of *kharif* and rabi crops. Occasionally, the operator of a state tube well is tipped regularly to prevent his reporting private tube well owners within the command area of the state tube well who can not legally supply water to neighbors, but were doing so either for profit or because the state tube well is unable to fulfill the demand of the farmers.

lenders (table 10). Government and cooperatives accounted for only 14 percent of the financing. Those who borrowed from the government or cooperative sources usually obtained loans in less than 6 months, but 3 out of 11 required 6 months to a year to procure, and the loans averaged only Rs. 1,800, compared with an average of Rs. 3,800 per loan from the private moneylenders.

In general, the cultivators in the sample obtained electrical connections soon after application — less than 6 months in 70 percent of the cases, 6 months to a year in 25 percent, although 2 of 27 required over 2 years. One-third of the cultivators used influential persons to assist in obtaining electrical connections (table 11).

All the farmers complained about the frequent power failures that interrupt their irrigation plan (table 12). Also, 21 of 27 owners complained about theft of equipment or transformers and, hence, the need for some member of the family to keep watch nightly. A considerable number of farmers (19 out of 27) also complained about mechanical troubles and repair problems.

Table 10. Source of finance
(27 private tube wells, 1966–67)

Source of finance	Number of private tube wells	Quantity of funds (Rs.)	Percentage of total
Own	26	118,000	68
Moneylender	8	30,400	18
N.E.S. Block	8	14,500	8
Cooperative	3	10,800	6
Total	45*	173,700	100

*Adds to 45 rather than 27, due to multiple sources for nearly all wells not entirely self-financed.

Table 11. Sources of assistance in obtaining electrical connection
(27 private tube wells, 1966–67)

Source	Number of wells	Percent of total
Employee of the tube well department	2	7.00
Pradhan (village chief)	1	4.00
Moneylender	1	4.00
Member of the state assembly	5	18.00
None	18	67.00
Total	27	100.00

Table 12. **Problems faced by owners of private tube wells (27 wells, 1966–67)**

Problems	Number of farmers	Percentage over 27 wells
Power failure...	27	100
Watching pump house...	21	78
Mechanical breakdowns and disruption for repairs	19	70
Repayment of loans for establishing wells...	3	11
Shrinking of spring level...	3	11
Cumbersome procedure for paying energy charges	1	4
Waste of water from unlined channels...	1	4

Table 13. **Nature of breakdowns in private tube wells (27 wells, 1966–67)**

Items of breakdown	Number of cases reported	Percentage over 27 wells
Motor burn-out...	12	45.0
Brushes and ball-bearing breakdowns...	10	37.0
Damage to belts and pulleys...	8	30.0
Damage to pumps...	8	30.0
Damage to starter...	7	26.0
Switch out of order...	5	19.0
Valves out of order...	3	12.0

The most common breakdown was motor burn-out, reported by nearly half of the 27 well owners (table 13). This is probably related to severe fluctuations in voltage. Seventy percent of repairs are handled in nearby Aligarh, while a few cultivators go to Hathras or Delhi for repairs.

Operational Characteristics of Persian Wheel and Charsa Systems

Persian wheel systems averaged a discharge rate of 12 cubic meters per hour, but 15 percent averaged half this capacity, and 33 percent averaged 50 percent more than this rate. While actual delivery averaged 9,000 cubic meters in a year, 25 percent of the Persian wheel systems averaged only about 3,000 cubic meters, and 25 percent averaged about 17,000 cubic meters in a year. Most Persian wheel operations are entirely self-financed, with only 6 of the 44 wells receiving any financial aid from government or cooperative sources.

Three-quarters of the farmers complained of receding water in continuously used wells (table 14). Other problems mentioned by a large

Table 14. **Problems faced with Persian wheels (44 wells, 1966–67)**

Problems	Number of times reported	Percentage over total of 44 Persian wheels
Water level recedes with continuous use	34	77
Draft on bullocks	28	63
Cannot control larger area	28	63
Takes much human and bullock labor	24	54
Thefts	14	32
Intensive cultivation not possible	14	32
High initial investment	8	18

Table 15. **Alternative source of water preferred by Persian wheel farmers (44 wells, 1966–67)**

Alternative source of irrigation	Number of farmers	Percentage over total
State tube well	8	18
Private tube well (electrically driven)	29	66
Diesel engine pump set	3	7
Improved Persian wheel	4	9
Total	44	100

number of Persian wheel owners dealt with the low delivery capacity and high costs which affected cropping patterns, yields, and farm incomes.

Farmers were asked for a choice of alternative methods of irrigation to Persian wheel systems. Two-thirds expressed a liking for an electrically operated private tube well, because of its low cost of operation and independent control (table 15).

The average delivery rate of charsa systems was two-thirds that of Persian wheel operations. Like Persian wheel systems, they too have a problem of receding water level if continuously used. The wells with charsa are deeper than those with Persian wheels, so there is no possibility of change to a Persian wheel system. The alternative choice is a shift to mechanized lifting of water by diesel engine or the installation of an electrically driven tube well.

Chapter 3

Cropping Pattern and Yield

Cropping Pattern

Wheat is the most important crop grown by the sample farms. It comprises over one-third of the rabi acreage and one-fifth of the total crop acreage (table 16). Most of the remaining rabi acreage is planted to wheat and barley mixtures and various pulses. During the kharif season nearly one-third of the land is fallow. Bajra is the most important kharif crop, occupying one-third of the land under kharif crops; bajra and bajra mixtures take two-thirds of the acreage. Bajra is grown both for grain and fodder. Maize is the next most important kharif crop, taking about one-third as much acreage as bajra. The area studied is mostly higher, better drained land that produces higher yields of bajra and maize than jowar, which is grown on less well drained land. Only 2 percent of the total cropped acreage is under *zaid* crops and another 2 percent under perennial crops.

More intensive cropping patterns on the private tube well farms reflect the availability and reliability of the water supply. These farms grow more bajra and American cotton than farms irrigating from other sources, taking advantage of the opportunity for well-timed pre-monsoon irrigation. Practically all of the small acreage of hybrid bajra and maize is grown on farms irrigated by private tube wells; they have much less fallow land in kharif. Three times as high a proportion of dwarf wheat is grown on the private tube well irrigated farms as compared with state tube well irrigated farms; they have a 50 percent higher proportion of land in peas, which well-timed early irrigation after a *kharif* crop; and they have nearly 3 times the proportion of acreage in summer vegetables and a 50 percent larger proportion of acreage in perennial crops. The farms irrigated from state tube wells grow more drought-tolerant-bajra mixtures and wheat mixtures.

The charsa irrigated farms have the costliest, least readily available water supply and so they grow no new improved wheat varieties, no hybrid bajra, more bajra mixtures, and wheat and barley mixtures, and more unirrigated crops, such as arhar.

State tube well and Persian wheel irrigated farms are quite similar in their cropping patterns and lie intermediate between the charsa and the private tube well systems. This suggests that problems of uncertainty of water supply greatly restrict the potential for improved cropping of state tube well irrigated farms.

Table 16. **Proportion of area under various crops, by source of irrigation (141 farms, 1966–67)**

Crops	State tube well	Private tube well	Persian wheel	Charsa	Total
	Percent of total acreage				
Kharif crops:					
Bajra, desi	10.3	16.0	7.0	8.9	12.1
Bajra, hybrid	0.2	1.2	0.0	—	0.6
Bajra and arhar	6.6	1.1	5.4	4.4	3.6
Bajra mixtures with jowar and guar either for grain or fodder	4.2	4.6	6.0	11.9	5.5
Maize, desi	7.8	4.6	6.0	3.2	5.5
Maize, hybrid	—	1.9	—	0.5	0.9
Cotton, American	0.4	3.5	1.6	0.7	2.1
Misc. kharif crops	1.8	2.6	3.8	—	2.5
Kharif, fallow	16.0	11.2	18.6	19.8	14.7
Sub-total:	47.3	46.7	48.4	49.4	47.5
Rabi crops:					
Wheat, desi	12.7	11.6	9.9	9.9	11.3
Wheat, K-68	0.1	3.6	0.8	—	1.9
Wheat, Mexican	1.4	4.4	1.0	—	2.6
Wheat and gram	8.9	2.2	8.6	11.1	5.9
Mixtures of: wheat and barley, barley and gram, barley and peas	6.9	6.0	8.8	8.8	7.0
Gram	0.2	0.5	1.8	2.1	0.9
Peas	10.5	14.2	8.1	2.5	11.0
Arhar	6.8	1.4	6.2	9.7	4.4
Lucerne	0.0	0.2	0.1	0.0	0.1
Misc. rabi crops	1.0	1.7	2.4	1.5	1.7
Rabi, fallow	1.0	1.1	1.6	3.3	1.4
Sub-total:	49.5	46.9	49.3	48.9	48.2
Zaid crops:					
Tinda and other summer crops	1.4	3.7	0.1	1.0	2.1
Sub-total	1.4	3.7	0.1	1.0	2.1
Perennial crops:					
Orchards pure or inter-cropped with grain or fodder crops	0.3	1.5	0.5	0.5	0.9
Lucerne	0.1	0.1	0.1	—	0.1
Sugarcane	1.3	1.0	1.6	0.2	1.1
Misc. crops	0.1	0.1	—	—	0.1
Sub-total:	1.8	2.7	2.2	0.7	2.2
Grand total	100	100	100	100	100
Area (hectares) over which percentage has been computed	285	594	298	113	1,289

Effect of farm size on cropping pattern

There appears to be no significant difference between small- and medium-size farms using similar sources of irrigation, in either general cropping patterns or planting of new seed varieties. Even though small farmers using private tube well water generally purchase that water from farmers with larger holdings, those small farmers are just as progressive with respect to cropping pattern and seed variety as those with larger farms. In contrast, the small farms with a private tube well water supply appear much more progressive than small farms using state tube well water. On the small farms using private tube well water, two-thirds of their wheat acreage is planted in improved varieties, as compared with less than 10 percent for the small farmers taking water from state tube wells; and on those small farms with private tube well water, 15 percent of bajra and maize acreage is planted to hybrids, compared with about 3 percent for small farmers without private tube well water.

Relative importance of new wheat varieties

The most important innovation in farming in Uttar Pradesh in the last few years has been the introduction of new high-yielding Mexican (dwarf) varieties of wheat. These varieties respond well to high levels of fertilization, but require very precise timing of water application, and farmers normally give them more than twice as many irrigations as the desi varieties.

In 1966–67 nearly 25 percent of the wheat acreage under private tube well irrigation was planted to Mexican varieties and 20 percent was planted to K-68, an improved local variety (table 17). In contrast, under the high-cost water conditions of charsa irrigation no new varieties were planted. Problems of uncertainty probably cause farmers obtaining water from state tube wells to plant no more than 10 percent of their acreage

Table 17. **Proportion of area under different varieties of wheat, by source of irrigation (141 farms, 1966–67)**

Wheat variety	Source of irrigation				
	State tube well	Private tube well	Persian wheel	Charsa	Total
Wheat, desi	90	59	85	100	72
Wheat, K-68	*	18	7	—	12
Wheat, Mexican	10	23	8	—	16
Total	100	100	100	100	100
Area (hectares)	40	116	35	11	202

*Less than 1 percent.

with Mexican varieties, a proportion comparable to the Persian wheel irrigated farms.

A resurvey of these farms was made for the 1968–69 crop season. In the intervening 2 years the proportion of wheat acreage planted with Mexican varieties had increased from 23 percent to 70 percent on the farms irrigated from private tube wells (table 18). These farms had only 11 percent of the acreage planted to desi varieties. The state tube well and charsa irrigated farms still planted 29 and 31 percent of their acreage to desi varieties. In 1968–69 none of the *charsa* irrigated acreage was planted to Mexican wheats. It is notable that the new and preferred white Mexican varieties increased in importance by 1968–69; but while these varieties were in short supply, cultivators continued to grow the red varieties.

In 1966–67 size of farm was not associated with significant differences in use of new high-yielding varieties of crops. In 1968–69 the small farms appeared to plant a slightly lower percentage of their land to Mexican varieties (table 19). However, the differences are small and are probably due to a desire by the cultivators to grow enough of the higher quality desi varieties for home consumption needs. This would take a higher proportion of total wheat acreage on the smaller farms.

Relative importance of hybrid bajra

The small amount of hybrid bajra grown in 1966–67 was largely on farms irrigated with private tube well water (table 20). In contrast to wheat, the proportion of bajra acreage planted to hybrids did not increase in the 2 years up to 1968–69 (table 21). This suggests that even with the controlled supply of well water for early irrigation and planting, either

Table 18. **Proportion of area under high-yielding varieties of wheat, by source of irrigation**
(141 farms, 1968–69)

Wheat variety	Source of irrigation				
	State tube well	Private tube well	Persian wheel	Charsa	Total
	percent				
Desi	29	11	34	98	20
K-68	12	19	12	2	16
Red Mexican	25	18	21	—	20
White Mexican	34	52	33	—	44
Total	100	100	100	100	100
Area (hectares)	56	174	48	5	283

Table 19. **Proportion of area under high-yielding varieties of wheat, by source of irrigation and size of farm**
(141 farms, 1968–69)

Crop variety	State tube well		Private tube well			Persian wheel		Charsa		All	
	Small farms	Medium farms	Small farms	Medium farms	Large farms	Small farms	Medium farms	Small farms	Medium farms	Small farms	Medium farms
						percent					
Desi	38	25	19	12	8	34	34	100	97	30	24
K-68	15	11	22	22	16	14	11	—	3	17	21
Red Mexican	17	29	15	19	18	18	23	—	—	16	22
White Mexican	30	35	44	47	58	34	32	—	—	37	33
Total	100	100	100	100	100	100	100	100	100	100	100
Area (hectares)	17	39	24	56	94	18	30	0.4	4.5	60	129

Table 20. **Proportion of area under hybrid bajra, by sources of irrigation (141 farms, 1966–67)**

Variety	State tube well	Private tube well	Persian wheel	Charsa	Total
	percent				
Desi	98	93	99	100	95
Hybrid	2	7	1	—	5
Total	100	100	100	100	100
Area (hectares) from which percentage computed	30	103	21	10	164

Table 21. **Proportion of area under hybrid bajra, by source of irrigation (141 farms, 1968–69)**

Variety	State tube well	Private tube well	Persian wheel	Charsa	Total
	percent				
Desi	99	92	100	100	96
Hybrid	1	8	—	—	4
Total	100	100	100	100	100
Area (hectares) from which percentage computed	42	94	49	13	198

the hybrid varieties are not more profitable to grow than the desi varieties, or cultivators do not understand the changes in practices needed for high yields.

It is notable that in 1966–67, cultivators with small holdings grew a higher proportion of hybrid bajra than those with medium size holdings; by 1968–69 they had reduced their proportion relative to those with medium-size holdings.

Relative importance of hybrid maize

In 1966–67 nearly 30 percent of the maize acreage under private tube well irrigation was planted to hybrids (table 22). Surprisingly, 14 percent of the maize acreage under charsa irrigation was planted to hybrids. However, by 1968–69 none of the acreage irrigated by charsa was planted to hybrids and the land under private tube well irrigation had dropped back to 9 percent (table 23).

Table 22. **Proportion of area under hybrid maize, by source of irrigation (141 farms, 1966–67)**

Crop	Source of irrigation				
	State tube well	Private tube well	Persian wheel	Charsa	Total
	percent				
Maize, desi	100	71	100	86	86
Maize, hybrid	—	29	—	14	14
Total	100	100	100	100	100
Area (hectares) from which percentage computed	22	38	18	4	82

Table 23. **Proportion of area under hybrid maize, by source of irrigation (141 farms, 1968–69)**

Crop	Source of irrigation				
	State tube well	Private tube well	Persian wheel	Charsa	Total
	percent				
Desi	98	91	99	100	95
Hybrid	2	9	1	—	5
Total	100	100	100	100	100
Area (hectares) from which percentage computed	20	39	13	1	73

Effect on cropping pattern of duration of private tube well use

Cropping patterns were analyzed for farms irrigated from private tube wells established in 1966, 1965, 1964, 1963, and earlier. No significant differences were found. This suggests that, given current conditions, there is not a significant period of adjustment of cropping patterns to the new conditions provided by the private tube well.

New crops introduced by users of private tube well water

Cultivators using private tube well water were asked to list the crops they had planted as a result of having a private tube well available. The results corroborate the conclusions of the earlier analysis (table 24).

Table 24. **New crops introduced by users of private tube wells (27 farms, 1966–67)**

Crops	Number of farmers	Percentage over total 27 wells
Wheat, Mexican	20	74
Maize, hybrid	15	56
Tinda	9	33
Vegetables, kharif, and rabi	6	22
Bajra, hybrid	5	19
Pea and lucerne	4	15
Tobacco	3	11
Potatoes	2	7
Perennials including sugarcane and orchards	2	7
Fodder, cotton, sweet potato, napier grass	1	4

Crop Yields

Crops grown on private tube well irrigated farms invariably had higher yields than farms irrigated from other sources. This is presumably because of the assured water supply, as well as the greater use of fertilizers.

The yield advantage for these farms is consistently more than 25 percent higher, even for the same variety. In addition, these farms plant a much higher percentage of their land to new, high-yielding varieties. On private tube well irrigated farms the yield from Mexican wheat was more than twice as high as from the desi varieties. The yield per acre of Mexican wheat with private tube well irrigation was nearly 3 times the yield of desi wheat with charsa irrigation.

The yields of hybrid bajra and maize from farms irrigated by private tube wells are more than double the yields for desi varieties. However, the hybrids were probably restricted to the most suitable land; they require large quantities of water before the rains and large quantities of fertilizer.

The average yields on farms irrigated by Persian wheels were consistently higher than yields from farms using state tube well water. This suggests that farmers using state tube wells do not get adequate water at the proper time. The Persian wheel farmer, although having a low discharge of water, is able to irrigate his fields when needed. Charsa farmers have the lowest yields of all, indicating the high cost of water, which is used very sparingly and combined with complementary inputs.

The average yield per hectare by size of holding and source of irrigation is given in table 25. It is doubtful if there are significant differences in yields between size classes within the same irrigation system. Small farms may have lower yields of desi wheat than medium and large farms, but on private tube well irrigated farms yields of Mexican wheat appear higher for small farms than for medium and large farms. This may indi-

Table 25. **Average yield of selected crops, by size of holding and source of irrigation**
(141 farms, 1966–67)

Crops	Source of irrigation									Overall average
	State tube wells		Private tube wells			Persian wheel		Charsa		
	Small farms	Medium farms	Small farms	Medium farms	Large farms	Small farms	Medium farms	Small farms	Medium farms	
	quintals per hectare									
Bajra, desi	6	7	10	11	9	7	10	8	6	9
Bajra, hybrid	—	—	25	24	17	—	—	—	—	17
Maize, desi	8	6	11	8	9	9	7	—	—	8
Maize, hybrid	—	—	—	—	20	—	—	—	—	20
American cotton	—	—	—	9	6	—	—	—	—	7
Wheat, desi	11	15	12	18	16	13	17	12	12	15
Wheat, K-68	—	—	23	26	24	—	—	—	—	23
Wheat, Mexican	—	—	42	33	32	—	—	—	—	34
Wheat and gram mix	13	9	—	14	15	11	13	11	9	12
Barley	7	9	14	16	15	12	12	—	—	13
Barley and pea	10	—	—	13	16	10	12	—	—	11
Peas	6	5	14	12	7	6	9	—	—	8
Potatoes	—	—	—	62	31	—	—	—	—	41

Note: Observations less than 8 not recorded.

Table 26. **Proportion of gross value of production from various crops, by source of irrigation**
(141 farms, 1966–67)

Crops	State tube well	Private tube well	Persian wheel	Charsa	Total
			percent		
Kharif crops:					
Bajra, desi	9.9	12.4	7.9	10.9	11.0
Bajra, hybrid	0.4	2.0	0.1	—	1.3
Bajra and arhar	4.7	0.8	4.4	5.6	2.4
Bajra mixtures with jowar and guar, for either grain or fodder	4.3	3.9	7.6	14.9	5.3
Maize, desi	5.7	2.6	3.9	3.0	3.4
Mazie, hybrid	—	2.0	—	0.1	1.2
American cotton	0.6	5.8	4.3	2.1	4.5
Misc. kharif crops	2.6	1.4	3.5	—	1.9
Kharif, fallow	—	—	—	—	—
Sub-total	28.2	30.9	31.7	36.6	31.0
Rabi crops:					
Wheat, desi	27.3	18.6	22.9	25.0	21.2
Wheat, K-68	0.4	8.3	2.0	—	5.3
Wheat, Mexican	7.3	12.2	3.6	—	9.0
Wheat and gram	16.2	2.8	13.4	18.1	7.9
Mixtures of: Wheat and barley Barley and gram Barley and peas	7.1	6.4	10.2	12.4	7.6
Gram	0.1	0.2	0.6	1.7	0.4
Peas	7.2	10.8	6.7	2.3	8.9
Arhar	0.3	0.3	1.4	0.5	0.5
Lucerne and berseem	0.0	0.5	0.2	0.2	0.4
Misc. rabi crops	0.7	2.4	2.5	1.7	2.1
Rabi, fallow	—	—	—	—	—
Sub-total	66.6	62.5	63.5	61.9	63.3
Zaid crops:					
Tinda and other summer crops	0.8	2.3	0.3	0.8	1.6
Sub-total	0.8	2.3	0.3	0.8	1.6
Perennial crops:					
Orchards alone or with grain or fodder crops	0.4	2.0	0.4	0.4	1.3
Lucerne	1.0	0.4	0.2	—	0.4
Sugarcane	2.9	1.8	3.9	0.3	2.3
Misc. crops	0.1	0.1	—	—	0.1
Sub-total	4.4	4.3	4.5	0.7	4.1
Grand total	100	100	100	100	100
Value from which percentage computed (1,000 Rs.)	157	565	190	56	968

cate that more care in supervision and management is needed for Mexican wheat, something the small farmers can provide.

Gross Value of Crops Under Various Sources of Irrigation

The gross value of production of crops has been computed by multiplying production by an estimated "normal" price for main and by-products. Table 26 gives the proportion of the gross value of crop production by irrigation source.

Rabi season accounts for about 64 percent of the total gross returns; the share of *kharif* is only 31 percent. Wheat contributes about 35 percent of the value of production, while its share in the total cultivated area was

Table 27. **Proportion of gross value and gross cropped area, by source of irrigation (141 farms, 1966–67)**

Source of irrigation	Proportion of:	
	Gross value of crops	Gross cropped area
State tube well	16	22
Private tube well	58	46
Persian wheel	20	23
Charsa	6	9
Total	100	100
Value or area over which percentage has been computed	968,000 (Rs.)	1,289 (hectares)

Table 28. **Proportion of gross value under different varieties of wheat, by source of irrigation (141 farms, 1966–67)**

Crop variety	Source of irrigation				
	State tube well	Private tube well	Persian wheel	Charsa	Total
Desi	78	48	80	100	60
K-68	1	21	7	—	15
Mexican	21	31	13	—	25
Total	100	100	100	100	100
Gross value (1,000 Rs.) from which percentages computed	55	221	54	14	344

only about 16 percent. Next in importance are the mixtures of wheat and barley, accounting for about 15 percent of the annual gross returns. Peas accounted for a little less than 10 percent of the gross returns. Among the kharif crops, bajra and its mixtures accounted for about 20 percent of the annual gross returns, or about 70 percent of the kharif income.

The result of greater crop intensity and higher yields associated with private tube well irrigation is apparent in table 27. Farms irrigated from

Table 29. **Gross returns per hectare of various crops under different sources of irrigation**
(141 farms, 1966–67)

Crops	Source of irrigation:				
	State tube well	Private tube well	Persian wheel	Charsa	Average
	Rs. per hectare				
Kharif crops:					
Bajra, desi	530	740	730	600	690
Bajra, hybrid	—	1,600	—	—	1,500
Bajra and arhara	400	700	500	600	500
Bajra mixtures with jowar and guar, for either fodder or grain	600	800	800	600	700
Maize, desi	400	540	400	—	460
Maize, hybrid	—	1,000	—	—	1,000
American cotton	—	1,600	—	—	1,600
Misc. crops	760	540	600		600
Rabi crops:					
Wheat, desi	1,200	1,500	1,500	1,200	1,400
Wheat, K-68	—	2,200	1,600	—	2,100
Wheat, Mexican	—	2,600	—	—	2,640
Wheat and gram	1,000	1,200	1,000	800	1,000
Mixtures of:					
Wheat and barley Barley and gram Barley and pea	600	1,000	700	700	800
Gram	300	300	200	400	300
Peas	400	700	500	—	600
Arhar	30	200	150	30	100
Berseem and lucerne	—	—	—	—	—
Misc. crops	400	1,300	700	500	900
Zaid crops					
Tinda and other summer crops	330	610	—	—	570
Perennial crops:					
Orchards alone or with grain or fodder crops	—	1,200	—	—	1,000
Sugarcane	1,200	1,700	—	—	1,500
Misc. crops	600	1,600	—	—	1,200

Note: No data given if observations are less than 8.

private tube wells occupy 46 percent of the sample area, but produce 58 percent of the value of output. Farms irrigated from state tube wells and Persian wheels occupy about the same proportionate area, but the state tube well irrigated farms produce a 20 percent smaller proportion of the gross value of output. The charsa irrigated farms produce only two-thirds as much value of output per acre as the average of all farms.

The result of planting high-yielding wheat varieties is apparent from the relatively high proportion of the value of production from them (table 28). Sixteen percent of the area under Mexican varieties of wheat produces 25 percent of the output in this sample of farms.

Gross Value Per Hectare of Different Crops Under Various Sources of Irrigation

Gross value per hectare of crops under various sources of irrigation is given in table 29. Mexican wheat at Rs. 2,600 per hectare has the highest gross return per acre of all the crops in this sample. Next in importance is the local high-yielding variety of wheat, K-68, which gives an average of Rs. 2,100 per hectare as gross income.

Farmers irrigating from a state tube well reap lower gross returns per hectare on almost all crops than farmers irrigating from private tube wells. For many crops the gross returns per hectare on farms using state tube wells are lower than those irrigating with Persian wheel or charsa systems. Gross returns per hectare are low for farms irrigated by state tube wells. This shows the importance of the availability of an adequate and timely water supply, which in turn affects fertilizer use and other management practices that bring higher yields and, hence, higher returns.

Chapter 4

Farm Practices and Response to Inputs

Farm Practices and Input Use

Kilograms of nitrogen used per hectare on various crops is given in table 30. Most farmers used much higher applications of nitrogen on high-yielding varieties, such as hybrid bajra, hybrid maize, Mexican wheat, and K-68 wheat, as compared with local varieties. Farmers irrigating from private tube wells used nearly 3 times as much nitrogen per hectare on Mexican wheats as on desi wheats. The contrast was even sharper for those irrigating from other sources. Farmers with private tube wells used a higher application of nitrogen on almost all crops, compared with farmers using other sources of irrigation, evidently because of the

Table 30. **Nitrogen used on various crops under different sources of irrigation (141 farms, 1966–67)**

Crops	State tube well	Private tube well	Persian wheel	Charsa	Average
	kilograms per hectare				
Bajra, desi	2 (4)	7 (14)	2 (7)	2 (4)	5 (12)
Bajra, hybrid	—	53 (39)	—	—	48 (38)
Maize, desi	5 (9)	14 (19)	5 (14)	—	8 (15)
Maize, hybrid	—	75 (54)	—	—	72 (54)
American cotton	—	5 (9)	4 (7)	—	5 (10)
Wheat, desi	9 (13)	26 (31)	5 (10)	4 (7)	14 (24)
Wheat, K-68	—	56 (38)	—	—	52 (41)
Wheat, Mexican	66 (41)	76 (39)	44 (50)	—	70 (42)
Wheat and gram	4 (9)	6 (11)	1 (6)	1 (3)	3 (8)
Barley	6 (13)	21 (36)	2 (7)	—	11 (26)
Barley and peas	1 (4)	2 (4)	1 (3)	2 (7)	2 (4)
Peas	2 (7)	10 (22)	1 (6)	—	6 (17)

Note: Standard deviations in parentheses.

availability of a timely water supply. Farmers irrigating from a charsa system use essentially no nitrogenous fertilizer. Those irrigating from private tube wells used 3 times as much nitrogen per acre on desi wheat, 15 percent more on Mexican wheat, 5 times as much on peas, and 3 times as much on desi maize, as those irrigating from state tube wells.

Table 31 gives the gross water in millimeters pumped per hectare to various crops, as well as the number of irrigations given each crop. There is no significant difference in the frequency of irrigations for each crop on farms irrigated from private tube well, Persian wheel, or charsa systems. The high-yielding varieties of crops consistently received more irrigations than other varieties. The extra irrigation given Mexican wheat on farms irrigated by state tube wells was probably possible because Mexican wheat was grown primarily on farms of more influential farmers located near the wells, thus facilitating access to the water. Farms irrigated from state tube wells consistently provide about half as many irrigations as those irrigated from other sources. This probably reflects a less reliable supply of water from state tube wells.

Table 31. **Gross water pumped per hectare, various crops under different sources of irrigation***
(141 farms, 1966–67)

Crops	State tube well	Private tube well	Persian wheel	Charsa	Average
		millimeters			
Bajra, desi	121(1) (130)	136(2) (78)	68(1) (73)	12 (26)	113 (96)
Bajra, hybrid	—	170(3) (78)	—	—	157 (88)
Maize, desi	301(2) (205)	231(1) (128)	110(2) (98)	—	215 (173)
Maize, hybrid	—	286(4) (137)	—	—	276 (145)
American cotton	—	283(3) (121)	225(3) (160)	—	269 (130)
Wheat, desi	356(3) (107)	458(5) (157)	343(5) (169)	347(5) (178)	395 (160)
Wheat, K-68	—	438(6) (183)	—	—	422 (185)
Wheat, Mexican	370†(4) (121)	530(7) (176)	422†(7) (87)	—	496 (173)
Wheat and gram	347(3) (160)	408(5) (226)	349(4) (204)	188(3) (110)	338 (193)
Barley	252†(2) (106)	430(5) (179)	334(4) (342)	—	351 (232)
Barley and peas	239(2) (141)	330(4) (127)	220(3) (146)	288(4) (130)	262 (143)
Peas	296(2) (149)	335(4) (136)	278(4) (148)	—	313 (145)
Potatoes	—	670† (414)	—	—	626 (385)

*Figures in parentheses at right state number of irrigations; those below are standard deviations.

†Based on less than 12 observations.

The volume of water pumped per hectare of crop is substantially higher for a private tube well source than from all the other sources. Charsa irrigated farms apply very little water per hectare, except for desi wheat, for which the rates of application are comparable to all sources, except private tube wells. Farms irrigated by state tube wells use quantities of water per hectare similar to Persian wheel irrigated farms.

The quantity of water pumped for high-yielding varieties is significantly greater than for desi varieties. The contrast is less for farms irrigated by state tube wells.

The quantities of water reported here are gross, without allowance for seepage from channels or evaporation. No measure was made of irrigation efficiency. If one assumes an irrigation efficiency of 60 percent, the water use figures for each crop are comparable to commonly accepted levels of water use under these conditions.

Table 32. **Quantity of nitrogen and water used per hectare by size of farm and source of irrigation**
(141 farms, 1966–67)

Source of irrigation	Nitrogen (kgs/hect)				Water (cu m/hect)				Total nitrogen* & water cost† (Rs./hect)			
	Small farms	Medium farms	Large farms	Ave.	Small farms	Medium farms	Large farms	Ave.	Small farms	Medium farms	Large farms	Ave.
State tube well........	10	10	—	10	4,000	4,000	—	4,000	157	157	—	157
Private tube well........	30	30	30	30	5,400	6,100	5,200	5,600	194	210	190	198
Persian wheel..	—	10	—	—	3,500	2,800	—	3,200	263	235	—	240
Charsa.....	—	—	—	—	2,300	1,800	—	2,000	276	216	—	240

*Cost of nitrogen taken as Rs. 2.50/kilogram.

†Cost of 1,000 cubic meters of water taken as follows (see table 9):

State tube well:	Rs. 33.00	Persian wheel:	Rs. 75.00
Private tube well:	Rs. 22.00	Charsa:	Rs.120.00

The only significant difference in level of nitrogen or water use among different sizes of farms occurs on the Persian wheel and charsa irrigated farms (table 32). In both cases, the small farms use about 25 percent more water per hectare than the medium-size farms. This is presumably because small farms have a greater surplus of bullock and human labor available for the arduous task of lifting water by these means.

Data were collected for several farm practices, including number of plowings and weedings. For the same crop and variety there is no significant difference in number of plowing from one water source to another, with the possible exception of charsa irrigated farms, which appear to give one less plowing on most crops. Neither is there a difference in number of plowings for high-yielding crop varieties and desi varieties. The wheat crop does, however, receive considerably more plowings (7 to 9) than other crops (3 to 6).

Rabi season crops on the sample farms consistently received one weeding in the year, irrespective of the source of irrigation or the variety. Kharif crops tend to receive more weedings because of the favorable conditions for weed growth during that season.

Functional Input–Output Relationships

To study the response of crop yields to different factors, the following variables were analyzed: (1) quantity of nitrogen; (2) volume of water in each month; (3) volume of water used in different groups of months; (4) total volume of water; (5) quantity of phosphorous; (6) quantity of potash; (7) area per permanent worker; (8) distance of the plot from source of irrigation; (9) number of plowings; (10) number of weedings.

The observations employed for the analysis were for unaveraged individual plots; a few hundred observations were used for many of the analyses. Nitrogen and water use were found to be closely intercorrelated. Water applied in different months was found to be intercorrelated. Nitrogen was intercorrelated with phosphorous and potash. Distance of the plot from the main source of irrigation was found to be intercorrelated with the total quantity of water. On the basis of careful study of the correlation matrices and a number of preliminary runs of the data, the analysis concentrated on 2 variables — nitrogen and total volume of water.

In general, linear functions were found best fitting and the analysis has been concentrated on them. Hence, particular care must be used in extrapolating results. Several linear equations were tried for almost all crops and sources of irrigation. Linear regression equations, in which the variable for water was found statistically significant, even if the variable for nitrogen was not significant, have been retained for discussion and are shown in tables 31 and 32. The correlation coefficients are invariably very low, although similar to those normally encountered with unaveraged plot observations under farm conditions. Quadratic functions and Cobb-Douglas functions were also tried and found less satisfactory.[2]

Crop yield and the single variable, water

Table 33 presents data for 9 equations relating total volume of water and crop yield. Two points become clear from these data.

First, the response to increments of water and associated inputs is much higher for the new high-yielding varieties than for desi varieties. For example, the water coefficient for Mexican wheat (equation 2) is nearly 4 times as large as for desi wheat (equation 1). The coefficients for water and hybrid bajra (equation 6) are nearly 5 times as large as that for desi bajra (equation 5).

Secondly, the response to increments in water and associated inputs appears somewhat greater on farms irrigated by private tube wells than on other farms (compare equations 2 and 3 for Mexican wheat, and equations 8 and 9 for desi maize). The higher response to private tube well irrigation probably reflects better control and timeliness of water application.

Crop yields and the 2 variables, water and fertilizer

Table 34 presents data for 8 equations relating total volume of water and quantity of fertilizer to crop yields. As expected, the coefficient for water is reduced, although only slightly, by separating the effect of nitrogen. (Compare equations 2 and 3 from tables 32 and 33, for all sources and private tube well irrigation of Mexican wheat.)

The relationships in table 32 continue to hold for table 33. The response coefficient for water is higher for irrigation by private tube wells than by other sources. (Compare equations 2 and 3, and equations 6 and 7). The high-yielding varieties have higher response coefficients for water than the desi varieties. (Compare equations 3 and 2 with 1 for an approximation of this.)

The response coefficient for water is particularly high for Mexican wheat (equations 2 and 3) and desi maize (equation 8) and expectedly low for a mixture of grain and wheat (equation 4).

In most cases the response coefficient for nitrogen was not statistically significant. The high coefficient for desi wheat suggests possible high returns for further increments of nitrogen over the low levels currently applied. The high response from peas when irrigated by state tube wells suggests that low applications of nitrogen produces good yields by giving an early rapid start to the seedlings. Similarly, the low response to nitrogen shown by this linear function for Mexican wheat grown on farms irrigated by private tube wells suggests that high levels of application used

[2]For a detailed report of these results, see *A comparative study of well irrigation in Aligarh, District, India*, by T. V. Moorti. (Dept. Agr. Econ., Cornell Univ., USAID Prices Res. Proj. Occ. Pap. 29, March 1970).

Table 33. **Linear relationships of crop yield to total volume of irrigation water, different sources of irrigation (141 farms, 1966–67)**

Equation number	Crop (no. observations)	Source of irrigation	Constant term	Value of regression coefficient (standard error in parens)	R^2	F value	Mean values of variables (standard deviations in parens)	
							Yield	X
1	wheat, desi (314)	all	12.4858	0.5442* (0.2028)	.02**	7.2	14.63 (5.79)	3.948 (1.597)
2	wheat, Mexican (79)	all	23.3030	2.1202** (0.6424)	.12**	10.89	33.81 (10.44)	4.955 (1.733)
3	wheat, Mexican (58)	private tube well	20.9886	2.4988* (0.7307)	.17		34.23 (10.56)	5.300 (1.756)
4	barley (30)	state tube well	4.2334	1.[illegible]936*	.13		8.50	2.521
5	bajra, desi (84)	private tube well	7.8821	1.3644* (0.6334)	.03		9.74	1.362
6	bajra, hybrid (16)	private tube well	8.3387	6.4353** (1.9720)	.43**	10.64	19.31 (7.65)	1.704 (0.782)
7	bajra, desi (51)	Persian wheel	7.6287	2.1125* (0.7781)	.13**	7.37	9.07 (4.29)	0.683 (0.734)
8	maize, desi (154)	all	6.8552	0.5901*	.04		8.12	2.149
9	maize, desi (47)	private tube well	6.2650	1.2964* (0.6006)	.08		9.26	2.306

Note: Y = yield in kilograms/hectare.
X = water volume in cubic meters/hectare.
*Significant at 5% level of probability.
**Significant at 1% level of probability.

Table 34. **Linear relationship of crop yield to nitrogen and total quantity of water, different sources of irrigation (141 farms, 1966–67)**

Equation number	Crop (no. observations)	Source of irrigation	Constant term	Value of regression coefficients (standard error in parens)		R^2	F value	Mean values of variables (standard deviations in parens)		
				X_1	X_2			Y	X_1	X_2
1.	wheat, desi (75)	Persian wheel	10.9595	0.1846** (0.0626)	1.0041** (0.3766)	.19**	8.42	1538 (598)	5 (10)	3427 (1688)
2.	wheat, Mexican (79)	all	20.0727	0.0567* (0.0258)	1.9640* (0.6308)	.18**	8.15	3381 (1044)	70 (42)	4955 (1733)
3.	wheat, Mexican (58)	private tube well	18.6171	0.0387 (0.0328)	2.3893** (0.7341)	.19**	6.58	3423 (1056)	76 (39)	5300 (1756)
4.	wheat + gram (172)	all	9.7327	0.0651 (0.0434)	0.4516* (0.1815)	.05*	4.40	1146 (468)	3 (8)	3382 (1934)
5.	peas (300)	all	4.8591	0.0438* (0.0212)	0.9786** (0.2503)	.07*	11.88	820 (635)	6 (17)	3127 (1447)
6.	peas (73)	state tube well	2.3570	0.0994 (0.0709)	1.0341** (0.3248)	.15**	5.98	563 (437)	2 (7)	2960 (1486)
7.	peas (59)	private tube well	4.6185	0.0096 (0.0249)	1.4842** (0.4013)	.09**	7.91	968 (689)	10 (22)	3348 (1363)
8.	maize, desi (45)	Persian wheel	5.3833	0.0197 (0.0370)	2.2077** (0.5382)	.30**	9.15	790 (404)	5 (14)	1096 (978)

Note: Y = Yield in kilograms/hectare; X_1 = nitrogen in kilograms/hectare; X_2 = total water in cubic meters/hectare.

*Significant at 5% level of probability.

**Significant at 1% level of probability.

Table 35. **Marginal returns to water from different sources of irrigation**
(141 farms, 1966–67)

Crop	Source of irrigation	Marginal physical products (quint/ 1,000 cu m water)	Price per quintal		Production ratio of main product to by-product	Marginal returns (rs./ 1,000 cu m water)
			Main product	By-product		
Bajra, desi	private tube well	1.36	56.00	8.00	1:3	109.00
Bajra, desi	Persian wheel	2.11	56.00	8.00	1:3	169.00
Bajra, hybrid	private tube well	6.44	56.00	8.00	1:3	515.00
Maize, desi	Persian wheel	2.20	51.00	5.50	1:2	128.00
Maize, desi	private tube well	1.30	51.00	5.50	1:2	42.00
Wheat plus gram	all	0.45	69.00	8.00	1:1	35.00
Peas	state tube well	1.03	68.00	4.00	1:1	74.00
Peas	private tube well	1.48	68.00	4.00	1:1	107.00
Peas	all	0.97	68.00	4.00	1:1	70.00
Wheat, desi*	all	0.54	70.00	11.00	1:2	42.00
Wheat, Mexican*	private tube well	2.50	63.00	11.00	1:1.25	162.00
Wheat, Mexican*	all	2.12	63.00	11.00	1:1.25	135.00

*These calculations of marginal returns are based on equations in table 33. All others based on equations in table 34.

with existing practices produce low returns. This indicates that farmers applying high levels of nitrogen may reduce their applications in the future.

Marginal returns to water use

Table 35 presents calculations of returns to water use derived from the physical response coefficients for the linear equations and the prices derived and presented in chapter 1. Since these are all linear functions, marginal and average values are identical. Particular care must be taken in extrapolating at the extremes of the data.

Chapter 2 gave the cost of 1,000 cubic meters of water for operations using state tube wells, private tube wells, Persian wheels, and charsa as Rs. 33.00, Rs. 22.00, Rs. 75.00, and Rs. 120.00, respectively. Using these costs and the returns listed in table 34, the ratios of return over cost have been calculated (table 36).

Table 36. **Return over cost of water for various crops from different sources of irrigation**
(141 farms, 1966–67)

Crops	State tube well	Private tube well	Persian wheel	Charsa
Bajra, desi	—	1:5	1:2	—
Bajra, hybrid	—	1:25	—	—
Maize, desi	—	1:2	1:1.5	—
Wheat and gram	1:1†	1:1.5	—	—
Peas*	1:2	1:5 1:3(all)	1:1	—
Wheat, desi	1:1.3†	1:2	—	—
Wheat, Mexican*	1:4†	1:7 1:6(all)	1:1.5†	1:1†

*Ratios calculated by taking relevant function for private tube wells (in parentheses) and function for aggregate sample (all).

†Marginal returns from aggregate sample used to find ratio.

The ratio of returns over cost is greatest for hybrid bajra and very high for desi bajra, suggesting that there is a considerable potential to increase production of these crops with higher levels of water use. This may be particularly true of early planted bajra.

The ratio of returns over cost were also very high for Mexican wheat, with the ratio successively higher for systems providing the most timely control of water — private tube wells, Persian wheel systems, and state tube wells, respectively. The Mexican wheats greatly increase the returns to private tube well water, relative to other systems, and thereby greatly increase the incentive to install private tube wells.

Chapter 5

Gross and Net Farm Returns

Gross Returns per Permanent Farm Worker

Gross value of output per permanent farm worker increases with an increase in farm size, indicating the fuller employment provided by a larger farm (table 37). This contrast is much greater for farms irrigated by private tube wells. Because the Persian wheel and charsa sources of irrigation offer more scope for employment of labor in pumping water, a greater volume of water is used per hectare on small farms as compared with medium ones employing these irrigation systems. Medium-size farms have over twice the gross of small farms within the private tube well category, a slightly lower gross within the charsa category, about a 50 percent higher gross within the Persian wheel category, and an 80 percent higher gross within the state tube well category. Medium-size farms average a 130 percent larger area than small ones. The introduction of private tube wells increases gross income of small farm operators, but also further widens the income gap between themselves and operators of larger farms.

Table 37 shows the limited improvement provided by the state tube wells. Small farms using water from state tube wells have smaller gross incomes than small farms using water supplied by a Persian wheel operation; for medium-size farms the gross income per farm worker is the same. In contrast, small farms with private tube well water have a 10 percent higher gross income than those with Persian wheel irrigation, while for the medium-size holdings the farms irrigated by private tube wells have gross incomes per permanent farm worker nearly 50 percent higher than those irrigated by Persian wheels.

Table 37. **Gross value of output per permanent farm worker, by size of farm and source of irrigation (141 farms, 1966–67)**

Source of irrigation	Size of farm		
	Small	Medium	Large
	rupees/permanent worker		
State tube well	1,600	2,900	—
Private tube well	2,100	4,300	6,100
Persian wheel	1,900	2,900	—
Charsa	1,900	1,800	—
Average	1,900	3,200	6,100

Gross and Net Returns Per Hectare

Table 38 shows the returns per hectare after subtracting the cost of fertilizer and water. Fertilizer and water are the two most important inputs influencing production. Column A lists water at cost; column B lists water at market prices. Market price is lower than cost for the state tube wells and higher than cost for the private tube wells.

Table 38. Gross and net returns per hectare, by source of irrigation (141 farms, 1966–67)

Source of irrigation	Quantity nitrogen (kg/hect)	Quantity water (cu m/hect)	Total cost nitrogen* and water† (rs./hect)	Gross returns (rs./hect)	Net returns (rs./hect)	
					A	B
State tube well.....	10	4,000	157	1,067	910	960
Private tube well. .	30	5,600	198	1,898	1,700	1,660
Persian wheel... .	--	3,200	240	1,200	960	—
Charsa.........	--	2,000	240	900	660	—

*Cost of nitrogen: Rs. 2.50/kg.

†Cost of water per 1,000 cubic meters: is (see table 9):
State tube well: Rs. 33.00 Persian wheel: Rs. 75.00
Private tube well: Rs. 22.00 Charsa: Rs.120.00

‡Cost of water: market price of Rs. 30 per 1,000 cubic meters for private tube wells and Rs. 20 per 1,000 cubic meters (Rs. 14 state charge and Rs. 6 bakshish) for state tube wells; fertilizer cost same as above.

"Net" returns per hectare are still 70 percent higher for the farms irrigated by private tube wells than for those irrigated by state tube wells. The latter are slightly lower than the Persian wheel system irrigated farms and nearly 50 percent higher than those irrigated by a charsa system. From earlier analysis it is clear that these results will not differ much between various farm sizes.

Farmers irrigating by a charsa operation are likely to prefer water from a state tube well because of the potential for lower cost and larger gross income. Persian wheel farmers may prefer state tube well water because of lower cost, despite the greater uncertainty of supply, and a consequent potential for lower gross production. All farmers prefer private tube well water even at the market price relationships prevailing. These disparities may be reduced as farmers learn how to grow high-yielding varieties under state tube well conditions and as management of these wells improves. However, because of the high capital costs of state tube wells, large losses result if the size of irrigated areas and the total water pumped are both reduced in order to give greater certainty of supply. This is the dilemma of the state tube wells.

Relationship Between Gross Value of Output and Specified Inputs

After examining a large number of variables, the following were used to explain variation in gross farm returns: (1) quantity of nitrogen; (2) volume of total water; (3) human labor for weeding; and (4) human labor for weeding and plowing. The latter 2 variables were chosen from several alternatives to serve as proxies for labor input.

Zero order correlation matrices for 2 sets of variables are presented in tables 39 and 40 to help isolate suitable variables to be used in the study of the value of gross returns.

The correlation coefficients presented in the tables are all significant at a 1 percent level of probability. There is substantial intercorrelation among variables which must be taken into account in the analysis. The greatest intercorrelation is between the water and fertilizer variables and the labor inputs on weeding and plowing.

Linear regression functions with gross returns per hectare as the dependent variable; and fertilizer, water, and labor as independent variables, are presented in table 41. These functions have been run using all 141 farms as observations.

In function 1, volume of water has been used as the only explanatory variable. The coefficient of multiple determination of .26 suggests that about 26 percent of the variation in gross returns per hectare is due to

Table 39. **Correlation matrices, returns per hectare and various independent variables**

Variables	Y	X_1	X_2	X_3
Y	1.00	0.63	0.50	0.58
X_1		1.00	0.47	0.55
X_2			1.00	0.56
X_3				1.00

Note: Y = gross returns per hectare in rupees; X_1 = nitrogen in kilograms/hectare; X_2 = water in cubic meters/hectare; X_3 = human labor units for weeding/hectare.

Table 40. **Correlation matrices; returns per hectare and various independent variables**

Variables	Y	X_1	X_2	X_3
Y	1.00	0.63	0.50	0.58
X_1		1.00	0.47	0.57
X_2			1.00	0.61
X_3				1.00

Note: Y = gross returns per hectare in rupees; X_1 = nitrogen in kilograms/hectare; X_2 = water in cubic meters/hectare; X_3 = human labor units for weeding and ploughing/hectare.

Table 41. **Linear relationship of gross returns per hectare with inputs of nitrogen and water (141 farms, 1966–67)**

Function number	Constant term	Value of regression coefficients (standard error in parens)		R_2	F value	Mean of variables	
		Nitrogen (kg/hect)	Water (cu m/hect)			Nitrogen (kg/hect)	Water (cu m/hect)
1..............................	726.9134	—	0.1606** (0.0233)	.26**	47.76	—	4.100
2.......	1119.7676	18.4853** (1.9527)	—	.39**	89.61	14.6	—
3..............................	818.4808	14.7435** (2.1103)	0.0862** (0.0228)	.45**	56.29	14.6	4.100

**Statistically significant at 1% level of probability.

Table 42. **Linear relationship of gross returns per hectare with inputs of nitrogen, water, and labor (141 farms, 1966–67)**

Function no.	Constant term	Value of regression coefficients (standard errors in parentheses)					R^2	F value
		X_1 Nitrogen (kg/hect)	X_2 Water (cu m/hect)	X_3 Hectare (per permanent farm worker)	X_4 Labor (weeding units/hect)	X_5 Human labor (weeding & ploughing units/hect)		
4.	726.0133	13.5236** (2.2106)	—	—	21.7438** (5.3016)	—	.46**	58.32
5.	925.6800	15.1568** (2.1281)	0.0832** (0.0228)	−43.6625 (33.2062)	—	—	.46**	38.30
6.	623.6074	12.2701** (2.2360)	0.0582* (0.0243)	—	16.1762** (5.7086)	—	.48**	42.12
7.	439.0083	11.9836** (2.2497)	0.0506** (0.0251)	—	—	12.5912** (4.2076)	.48**	42.68

*Significant at 5% level of probability.
**Significant at 1% level of probability.

volume of water used and accompanying complementary inputs. The regression coefficient, which is statistically significant at a 1 percent level of probability, indicates that an additional cubic meter of water and accompanying complementary inputs increase the gross returns by Rs. 0.16.

In function 2, nitrogen has been substituted for water as the explanatory variable. About 40 percent of the variation in gross returns per hectare is attributable to nitrogen and its complementary inputs. The regression coefficient suggests that an additional kilogram of nitrogen and its complements would add about Rs. 18 to the gross returns per hectare.

In function 3, both nitrogen and water have been included to explain the variation in gross returns. Both coefficients are statistically significant at a 1 percent level of probability; the R^2 has been increased to .45.

Regression functions including various proxies for labor are presented in table 42. All the independent variables are statistically significant at 1 percent or 5 percent levels; the coefficient of multiple determination shows a slight improvement ranging from .46 to .48. The improvement in R^2 over equation 3 is, however, not significant and with substantial intercorrelation between the labor proxies and nitrogen or water, equation 3 is used for further analysis. Throughout the analysis it must be remembered that each of the 2 independent variables serves as a proxy for other variables. Nitrogen, for example, carries the effect of phosphorous and potash. Hence the response coefficients should not be compared solely with the cost of the single variable.

Both linear and logarithmic (Cobb-Douglas) functions have been used for analysis, with farms stratified by sources of irrigation (table 43). All the logarithmic equations but one have a substantially lower R^2 compared with the corresponding linear equations, suggesting that the latter functions are not readily applicable to the data. Further discussion will deal only with the linear equations.

The results of equations 8 through 11 are, as expected, from the previous analysis. A relatively low coefficient for nitrogen in the private tube well equation is consistent with the already very high rates of nitrogen use on these farms. Successively higher coefficients on the state tube well, Persian wheel, and charsa operated farms show the successively lower levels of fertilizer use in these groups. Despite the greater cost, lesser quantity, or poorer control of water on these sets of farms, by applying more fertilizer they would profit more at their current margins than the private tube well farms, although it might not be profitable for these groups to go to the high rates of application used on the private tube well farms.

The ratios of the marginal value products for nitrogen and water (calculated from the linear equations in table 43) to the costs of nitrogen and water are given in table 44.

Table 43. **Relationship of gross returns per hectare with inputs of nitrogen and water, by sources of irrigation (141 farms, 1966–67)**

Function number	Source of irrigation	No. observations	Linear function: Constant term	Linear function: X_1 Nitrogen (kg/hect)	Linear function: X_2 Water (cu m/hect)	Linear function: R^2 (F value)	Cobb-Douglas function: Constant term	Cobb-Douglas function: X_1 (kg/hect)	Cobb-Douglas function: X_2 (cu m/hect)	Cobb-Douglas function: R^2 (F value)
8..........	state tube well	36	684.9801	19.3217** (4.9086)	0.0603† (0.0319)	.37** (9.89)	34.5836	0.0230 (0.0184)	0.4095* (0.1556)	.21* (4.37)
9..........	private tube well	50	1038.6655	9.9484* (3.4260)	0.0959† (0.0499)	.28** (8.96)	68.2393	0.0458* (0.0217)	0.3658* (0.1534)	.28** (9.20)
10..........	Persian wheel	41	997.2742	29.6616** (7.6520)	0.0312 (0.0351)	.28** (7.36)	512.8519	0.0310* (0.0158)	0.1080 (0.0954)	.13 (2.79)
11..........	charsa	14	764.7388	35.5346 (23 8098)	0.0261 (0.9820)	.19 (1.27)	222.5865	−0.0084 (0.0454)	0.1810 (.01875))	.08* (4.66)
12..........	all farms	141	818.4808	14.7435** (2.1103)	0.0862** (0.0228)	.45** (56 29)	89.8689	0.0384** (0.0104)	0.3202** (0.0599)(	.33** (33.64)

*Significant at 5% level.
**Significant at 1% level.
†Significant at 10% level.
Figures in parentheses are standard errors.

Table 44. **Ratios of marginal value products and cost of nitrogen and water (141 farms, 1966–67)**

Source of irrigation	Marginal value products for:		Ratio of marginal value products to costs:	
	Nitrogen (rs./kg)	Water (rs./cu m)	Nitrogen	Water
State tube well	19.32	.060	1:8	1:2
Private tube well	9.94	0.96	1:4	1:4
Persian wheel	29.69	—	1:12	—
Charsa	—	—	—	—

Note: Cost of water/cubic meter: state tube well, .033; private tube well, .022; Persian wheel, .075; charsa, .12. Cost of nitrogen, Rs. 2.50/kg.

The coefficient for water is highest for farms with private tube wells, despite the fact that they use the greatest quantity of water per hectare. This suggests that the combination of good timing of application and control of water, substantial use of high-yielding responsive varieties of crops, and use of high levels of other inputs provides high returns to further increments of water even at high levels of use. Conversely, charsa system irrigated farms, which plant crops unresponsive to high levels of water input and which are deficient in other inputs, do not respond well to more application of water. Private tube wells provide large quantities of low cost water, which results in complementary changes in cropping patterns, the planting of new crop varieties and, the employment of new inputs; these serve to increase the volume of water that it is profitable to use, further production, and raise farm incomes.

The preceding analysis is further supported by the ratios of costs to returns presented in table 44. Returns over direct costs of nitrogen are 2 times as high on the state tube well farms and 3 times as high for the Persian wheel system farms. The net returns are, of course, not as attractive as appear here, because nitrogen is serving as a proxy for other inputs, including various nutrients, each of which has its own costs.

Returns over direct cost of water is twice as high for the farms with private tube wells as for those with state tube wells, reflecting the high level of complements and the water-responsive cropping pattern.

Chapter 6

Profitability of Private Tube Wells and Problems of State Tube Wells

The preceding analysis indicates that farms irrigated with private tube wells are operated in a more profitable manner than those with state tube wells. Farms with private tube wells have more intensive cropping patterns, grow a greater proportion of high-yielding varieties, and operate at much higher levels of input use.

Farmers operating with Persian wheels or state tube wells gain about the same benefit when they shift to a private tube well system; Persian wheel farmers realize no profit in shifting to state tube wells (table 45).

The returns on a private tube well system are quickly realized. By switching from a Persian wheel system to a private tube well, an increase in net income of Rs. 740 per hectare is gained. If we multiply this figure by the 4 hectares of a modal farm, we find that the total capital cost of Rs. 5,000 to Rs. 6,000 is gained in less than 2 years. By the same calculation, the charsa farmer regains his capital investment in a private tube well in 1½ years.

By multiplying the average volume of water pumped by a private tube well (5,600 cubic meters per hectare) times the difference in pumping cost between a Persian wheel system and a private tube well (Rs. 53 per 1,000 cubic meters), a more conservative estimate is taken and a saving of Rs. 295 per hectare, or nearly Rs. 1,200 for a modal-size farm of 4 hectares, and, hence, a return to capital in 4–6 years is realized. By the same calculations, the charsa farmer would regain his capital in 2 to 4 years by changing to a private tube well.

Table 45. Additional cash flow for changing from one source of irrigation to another (141 farms, 1966–67)

Original source of irrigation	New source of irrigation	Increase in net income hectare*
		rupees
State tube well	Private tube well	790
Persian wheel	State tube well	(–) 50
Persian wheel	Private tube well	740
Charsa	State tube well	250
Charsa	Persian wheel	300
Charsa	Private tube well	1,040

*Net income defined as total production at market prices, minus cost of fertilizer and water; other costs are land, family labor, or hired labor.

These high benefits from the private tube well, as compared with the state tube well, are based on the assumption that factors such as greater reliability and timeliness of irrigation are responsible for the difference in returns. The underlying problem of the state tube wells is the extremely high capital cost per unit of delivery capacity. Much of the unreliability results from efforts to spread that capital cost over a large volume of water pumped, which favors larger acreages irrigated, but poorer timing. Thus, raising returns to farmers will probably require a reduced area irrigated and less total water pumped per unit of delivery capacity (as is the case with private tube wells). This in turn will raise the per unit cost of the water. More timely availability might allow charges to increase to equal the charge on private tube wells, but that charge may be expected to fall close to average total cost, which is not much higher than the present state tube well charge, plus bakshish. Thus, the gross income of the state tube wells may well fall if they are operated to provide maximum net social returns. Farmers could afford to meet the full cost of this water, given the potential benefits, but they would be reluctant to do so if the much cheaper private tube wells were available.

It is obvious that returns are much greater from private tube wells if the capital cost relationships are considered. However, there is already a large investment in state tube wells, so it is important that their efficiency be increased.

Observed Problems of State Tube Wells

1. Overseers cannot supervise maintenance and repair work or other technical jobs because they are busy keeping records. Due to lack of quality control, the contractor's work is often inadequate.
2. Because small farmers are at the mercy of the village headman, or the pradhan, the thokbhandi (rotational) system is not practical.
3. Tube well operators do not usually reside near the well, as they are normally hired from outside the village and encounter problems such as lack of housing and facilities for children's education. One *kuprakshak* (caretaker of the well) is provided from the command area to help the operator. The helper gets an honorarium of Rs. 20.00 per month. Factionalism is said to result in favoritism on the part of the kuprakshak.
4. Since most farmers are illiterate, they keep poor records of irrigation time. Tube well operators sometimes transfer tube well time to other farmers for additional tips.
5. Depending on the number of private tube wells in the vicinity of a state tube well, the operator usually is tipped between 0.25 paise to 1 rupee per kachha bigha (or Rs. 3.00 to Rs. 12.00 per hectare, per

irrigation). Sometimes this payment is in the form of wheat, bhusa, or green fodder for the operator's cattle. This is a form of commission to the operator, but if this is the purpose it would be more useful to legally incorporate it in the fees as a means of ensuring prompt and impartial service.

6. Electrical breakdowns are common; cultivators must forfeit their claim to irrigation if their turn falls during this breakdown of electricity. The resultant long periods between irrigations discourage production of high-yielding varieties with their larger irrigation requirements.
7. Since many formalities have to be completed to get the mechanic to the well, repairs take a long time.
8. Spare parts are not readily available; the tube well usually remains idle for a long time before it is repaired.
9. Kaccha guls (channels) are frequently damaged and take much time to repair.
10. If the command areas are large, there is substantial waste of water since it is transported long distances.
11. No siphon is constructed within the village and sometimes guls pass over roads. When there is motor vehicle or bicycle traffic, guls are damaged and much water is wasted.
12. Transformer thefts are a more common problem for state tube wells than for private tube wells, presumably because there is less careful supervision.
13. Much money is spent every year in maintaining the approach roads which, according to the irrigation department, no one is allowed to use except the inspector of that department. But the village bullock carts do use these roads, adding to the wear.
14. By using a thin wire it is possible to make the electric meter inoperable. Operators take advantage of this technique to make extra money and the state incurs the loss.
15. It was found that it is possible to bypass the meter and connect the motor directly to the electrical outlet if the operator and electrician work together.

Area to Be Irrigated from State Tube Wells

State tube wells in the sample irrigate about 135 hectares of land during the rabi season and a somewhat smaller acreage during the kharif season. Private tube wells, with about half the delivery capacity per well of the state tube wells, irrigate an average of 20 hectares during the rabi season. If the ratio of area irrigated to delivery capacity for private tube wells were applied to state tube wells, they would be handling 40 hectares, or less than a third of the current acreage. It is possible that the private tube wells are not making optimal use of their water supply. The most economic way of operating might be to cover somewhat larger areas per unit of pumping capacity. However, there is a well-developed market for the sale of water, and therefore it is quite possible that the private tube wells are operating at optimum efficiency. The marked difference in returns from water use between the state and private tube wells is attributable in part to the availability of a continuous water supply from private tube wells. A decline in the acreage irrigated by the state tube wells could result in an increase in yield from the more amply irrigated land. This applies to areas where new high-yielding crop varieties are available. Before the recent introduction of these varieties, the manner of operation of the state tube wells was probably more optimal.

There are 3 advantages to be gained from a reduction in the area irrigated by the state tube wells. First, the potential would be increased for the provision of water to cultivators. As a result, farmers could undertake the risks of planting new crop varieties and of applying much higher input levels on their crops. They would realize much higher returns on the water that they apply.

Secondly, the number of farms serviced from an individual well would be reduced. If the well could irrigate 40 hectares and the average holding size was 4 hectares, only 10 farmers would use the total supply from one state tube well. Assuming that the state tube wells would serve cultivators with smaller than average holdings, we might have a maximum of about 20 cultivators per state tube well. This would facilitate the improved administration of the operation of the well which would, in turn, lead to better timing of application and certainty of water supply, and reduce the cost of operation of the state tube wells. Where it is possible to install private tube wells, there is no reason to be concerned about reduction in the number of farmers to be served from the state tube wells. Since the state tube wells have such extremely high capital costs, there is no advantage in being served by a state tube well, rather than by a private tube well. The basic problem is how to make maximum use of the present investment in state tube wells.

The third advantage of a decrease in the size of an irrigated area would be that less water would be lost as a result of being carried long distances in channels.

The primary disadvantage in reducing the area irrigated is the substantial reduction in revenue to the tube well. This could be balanced by an increase in net returns to cultivators through a switch to high-yielding varieties and more intensive use of inputs and more intensive cropping patterns. If the state tube wells were operated effectively with the assurance of a continuous water supply, then the charges for state tube well water could be increased somewhat from current levels. However, the relatively low cost of water from private tube wells is likely to set a ceiling on the extent to which the rates for state tube well water can be increased. Economic forces will compel cultivators to use water from private tube wells rather than from state tube wells if the state water becomes relatively more expensive. Users of water from the state tube wells should not be charged for the uneconomically high capital costs incurred by those wells.

It should be kept in mind, when considering revenue from the state tube wells, that it is their high capital investment which increases the average cost of operation. As a result, the economic pressures are to spread the water thinly to many areas and farmers in order to maximize returns per unit of water. This is one of the primary reasons why the use of water from the state tube wells compares more closely to the use from the high-cost Persian wheel and charsa systems and less to the water from low-cost sources, such as private tube wells.

Improved Administration of State Tube Wells

A second improvement needed in the state tube well system is in the area of administration. Reduction of the number of hectares irrigated by the wells can facilitate a major improvement in their administration. The administrators need to be made more responsive to the needs of the cultivators who use the water from the state tube wells. With a reduction in the area irrigated and, hence, a major reduction in the number of cultivators who are serviced from any one well, it should then be possible to develop a cohesive cooperative unit for operation of the well. Although it seems unrealistic to expect a whole village of even 40 or 50 cultivators to band together for effective operation of the well, it does not seem unrealistic to expect a smaller number of 10 or 20 to band together for this purpose. Most important to the improvement of administration of the state tube wells is the development of a system whereby the well operator devotes himself effectively to efficient operation of the well. If there were a cooperative unit running the well, it might be feasible to hire the operator from the village where the well is situated, to provide him with a training program for the operation of the well and its repair, and also to train him in improved agricultural practices. The operator could then devote himself to the operation of the well and to making minor repairs. He could also encourage the farmers to employ improved cultivation practices, which would make more effective use of the water supply.

It would be more profitable to pay the tube well operator a commission on the water pumped. This would obviously give him a strong incentive to keep the pump operating so that it could be used whenever cultivators wanted water. It would also give him an incentive to help cultivators procure the information needed to shift to more intensive cropping patterns that would use more water.

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1. Lele, Uma J., and Mellor, John W., *Estimates of Change and Causes of Change in Foodgrains Production, India, 1949–50 to 1960–61*, Cornell International Agricultural Development Bulletin 2.
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Appendix

Appendix Table 1. **Cost of water from state tube wells**
(Average 10 wells, 1966–67)

Items	Rupees	
Equipment (capital cost)	38,300	
Civil works (capital cost)	38,200	
Depreciation @ 5% on equipment	—	1,915
Depreciation @ 3% on civil works	—	1,146
Interest on equipment and civil works @ 10%	—	7,650
Total fixed costs (depreciation and interest)	—	10,711
Maintenance and repairs:		
Maintenance on civil works	800	
Maintenance on equipment	550	
Overhauling per year	250	
Establishment charges	2,000	
Audit and accounts charges on items equipment and maintenance @ 10%	135	
Misc. repairs and maintenance	25	
Total maintenance and repairs		3,760
Energy charges:		
Energy consumption @ 11 units (KWU) per hour for 4,000 hours) 44,000 units:		
Charges @ 5.5 paise/unit		2,420
Surcharge Rs. 150 per H.P. for 12 H.P.		1,800
Total energy charges per well		4,220
Total variable costs (maintenance, repair, energy charges)		7,980
Total costs (fixed and variable)		18,691
Water delivered per well: 565,000 cubic meters		—
Cost of 1,000 cubic meters		33

Note: 1,233.48 cubic meters equal to an acre foot; 100 cubic meters approximately an acre inch.

Appendix Table 2. **Cost of water from private, electrically driven, tube wells, (27 wells, 1966-67)**

Items	Rupees	
Equipment	3,000	
Civil works:		
Channels, etc.	700	
Boring, transport, and misc.	850	
Pump house tank	550	
Total	2,100	
Depreciation on equipment and civil works @ 10%	—	510
Interest charges on initial investment of Rs. 5,100 @ 10%	—	510
Total fixed costs		1,010
Maintenance and repairs per well	250	250
Energy charges: Total units consumed per year; 7,300 K.W.U. Charges @ 14 paise per unit	1,022	1,022
Total variable costs		1,272
Total costs (fixed and variable)		2,282
Average water delivered per well in 1 year: 103,000 cubic meters	—	—
Cost of 1,000 cubic meters	—	22

Appendix Table 3. **Cost of water from a Persian wheel system (44 wells, 1966–67)**

Items	Rupees	
Equipment	600	
Civil works:		
(replacement value of a well)	1,200	
Depreciation on equipment @ 15%	—	90.00
Depreciation on civil works @ 2%	—	24.00
Interest on total investment @ 10%	—	180.00
Total fixed costs	—	294.00
Maintenance and repairs of equipment	—	50.00
Labor charges for driving Persian wheel, 102 days @ Rs. 2.25	—	229.50
Extra feed cost for bullocks while working on Persian wheel (Rs. 1.50/day for 102 days)		153.50
Total variable costs		433.00
Total costs (fixed and variable)		727.00
Water delivered by Persian wheel in one year: 9,700 cubic meters		—
Cost per 1,000 cubic meters	—	75.00

Appendix Table 4. **Cost of water from a charsa system (14 wells, 1966–67)**

Items	Rupees	
Equipment:		
charsa	50.00	
ropes	25.00	
wheel	30.00	
yoke	10.00	
Total	115.00	
Civil works (replacement value of a well)	1,200.00	
Total investment	1,315.00	
Depreciation on equipment:		
charsa @ 50%	—	25.00
ropes @ 100%	—	25.00
wheel @ 10%	—	3.00
yoke @ 50%	—	5.00
Depreciation on well @ 2%	—	24.00
Interest charges on investment (equipment and civil works) @ 10%	—	131.00
Total fixed costs (depreciation and interest)	—	213.00
Maintenance and repairs (oil, etc.)	—	10.00
Two laborers for 108 days @ Rs. 3.00 per day		648.00
Extra feed cost for bullocks while drawing charsa (@ Rs. 1.50/day for 108 days)		162.00
Total variable costs (labor and feed)		820.00
Total costs (fixed and variable)		1,033.00
Total water delivered in 1 year: 8,600 cubic meters		—
Cost per 1,000 cubic meters		120.00