On-Farm Water Management for Rice-Based Farming Systems in Bangladesh

M. A. Ghani
Principal Agricultural Engineer, Irrigation and Water Management Division
Bangladesh Rice Research Institute, Gazipur, Bangladesh

M. K. Mondal
Senior Agricultural Engineer, Irrigation and Water Management Division
Bangladesh Rice Research Institute, Garipur, Bangladesh

Contributors

M. A. Rashid, Senior Agricultural Engineer
M. Nazrul Islam, Senior Agricultural Engineer
M. Nazmul Hassan, Senior Agricultural Engineer
Hamidur Rahman Molla, Agricultural Engineer
Golam Mowla, Agricultural Engineer
M. Towfiqul Islam, Agricultural Engineer
Nafis Jahan Joarder, Agricultural Engineer
L. R. Bhuiyan, Principal Agronomist
M. J. Islam, Senior Soil Physicist

Irrigation and Water Management Division
Bangladesh Rice Research Institute, Gazipur, Bangladesh.

INTRODUCTION

THE OPTIMUM USE of irrigation water should be an important strategy for increasing agricultural production in Bangladesh. The overall development of the country's agriculture sector will require year-round use of the irrigation facilities for productive use of water. The country will realize substantial benefits if the allocation and distribution of the available water are improved. Field studies are needed to identify the nature and magnitude of water management problems and to develop methods of improving water management, which would help achieve higher crop yields, higher irrigation efficiency and greater water distribution equity.

Research, conducted by the Bangladesh Rice Research Institute (BRRI) and the Bangladesh Water Development Board (BWDB) in collaboration with the International Rice Research Institute (IRRI), was started in November 1981 in two irrigation projects in Bangladesh-the Ganges-Kobadak (GK) Project (Phase I) and the North Bangladesh Tubewell Project (BTP). The International Irrigation Management Institute (IIMI) joined the collaborative project in 1988.

This paper highlights the results of the collaborative research, with the following objectives:

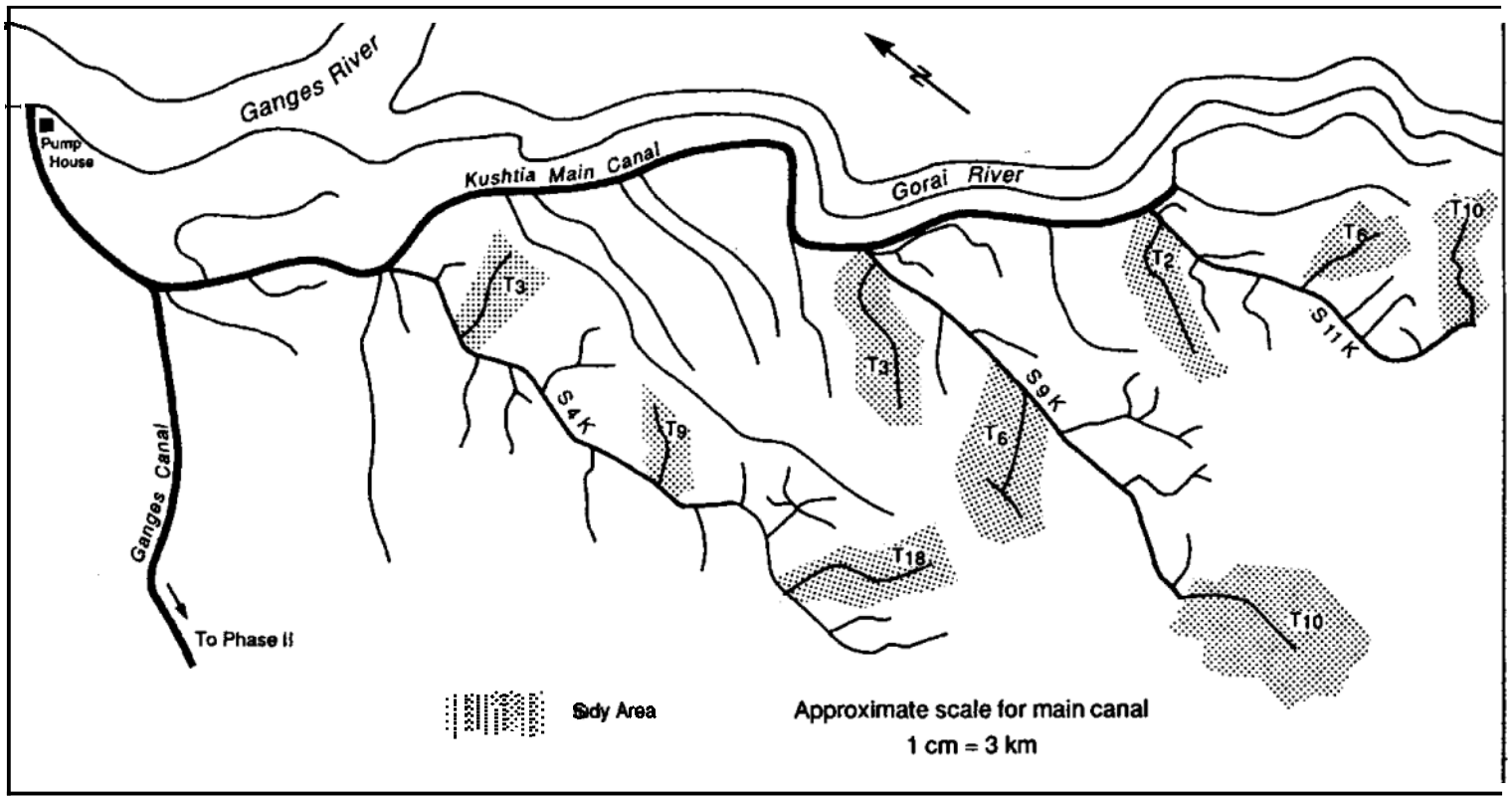
1. To establish the status of water utilization and crop production.
2. To identify and analyze strategies and methods followed in project operation and their effect on crop production.
3. To suggest improvement alternatives for increasing water use efficiency and crop production.

METHODOLOGY AND MEASUREMENTS

Research Sites

In the G-K Project (Phase I), the field-research sites are in the service areas of nine tertiary canals belonging to three secondary canals-the fourth, ninth and eleventh, respectively, representing the head, middle and tail reaches of the main canal. Three tertiaries were selected from each secondary to represent the head, middle and tail reaches of the secondary. The tertiaries are: T3, T9, T18 of S4K; T3, T6, T10 of S9K; and T2, T6, T10 of S11K (Figure 1).

Figure 1. chema Kobadak Bangladesh, showing selected secondary and



In the North Bangladesh Tubewell Project, field research was conducted mainly in 12 selected tubewells and their service areas which were chosen to represent the wholesystem. These "pilot" tubewells are: tubewell nos. 63, 77, 89, 93, 117, 118, 119, 120, 125, 126, 138 and 142. After the first phase of research in 1983, a pair of tubewells called "Satellit" was selected adjacent to each pilot tubewell for monitoring water- and crop-related parameters. Thus, 24 satellite tubewells (nos. 47, 48, 49, 53, 64, 65, 76, 88, 90, 91, 92, 95, 114, 121, 122, 123, 124, 127, 128, 129, 131, 133, 141 and 347) were included in the study.

Observation and Measurements

Fifty observation paddies were selected in each tertiary pilot tubewell area to represent the head, middle and tail reaches. Seasonal data on production status, use of inputs, and crop varieties were collected and analyzed.

Yields were assessed on the basis of crop-cuts taken in each season from the 50 selected plots of each of the nine tertiary/tubewell areas. A five-square-meter sample area was harvested from each plot, taking one square meter harvest each from five different locations of the plot. The harvest was threshed and grain yield measured. Moisture content of the grain was determined by a moisture meter. Yield was adjusted to 14 percent moisture content and expressed in kg/ha or ton/ha.

RESULTS AND DISCUSSION

The Ganges-Kobadak Project

Water utilization. The average rainfall recorded during land preparation vaned from 0.5 to 3.8 cm for the Aus and 1.2 to 15.2 cm for the Aman seasons (Tables 1, 2.3 and 4). The average irrigation delivery under research management was about 22 and 14 cm, for the Aus and Aman seasons, respectively. Under farmers' management, this corresponds to 24 and 15 cm, respectively. During the growing period (after seedling establishment prior to harvesting), rainfall was 69 and 58 cm in the Aus and Aman seasons, respectively. Irrigation delivery was 68 and 69 cm under research management and 83 and 81 under farmers' management in the Aus and Aman seasons, respectively. Water application values were higher for farmers' management as farmers did not maintain field levees properly which favored water loss.

Water use efficiency at field level varied from 36 to 69 percent in the Aus season and from 55 to 100 percent in the Aman season (Table 5). Low efficiency was observed near the head ends, possibly due to misuse of irrigation water. Water application values were higher for farmers' management as farmers did not maintain field areas properly. Average productivity of water during Aus was 2.86

Table 1. *Water used (mm) by farmers for land preparation and crop growth period in the selected locations of the Ganges-Kobadak Project (Phase 1) the Aus seasons, 1985-89.*

Location	1985			1986			1987			1988			1989		
	IR	RF	Total	IR	RF	Total	IR	RF	Total	IR	RF	Total	IR	RF	Total
	Land preparation														
T3/S4K							330	11	341	276	25	301	234	13	247
T0/S4K	262	08	270	231	30	261	327	07	334	290	00	290	273	10	283
T3/S9K							236	19	255	217	25	242	236	00	236
T6/S9K	315	00	315	282	23	305	262	00	262	198	42	240	240	00	240
T10/S9K							190	63	253	212	20	232			-
T2/S11K							127	105	232	133	21	154	213	00	213
T6/S11K	240	36	276	234	46	280	184	58	242	-	-				-
Mean	272	15	287	249	33	282	237	37	274	221	22	243	239	05	244
Location	Growing season														
T3/S4K							821	453	1,274	828	961	1,789	827	738	1,565
T9/S4K	828	496	1324	835	708	1,543	791	504	1,295	752	1,110	1,862	844	737	1,581
T3/S9K							705	604	1,309	376	1,273	1,649	605	678	1,283
T6/S9K	1,096	509	1,605	749	596	1,345	686	582	1,268	418	1,209	1,627	65	640	1,292
T10/S9K							666	628	1,294	606	1,141	1,547	-	-	-
T2/S11K							630	609	1,239	552	998	1,550	781	350	1,131
T6/S11K	1,651	379	2,306	1,299	603	1,902	476	802	1,278	-	-	-	-	-	-
Mean	1,192	461	1,653	961	636	1,579	682	597	1,280	555	1,115	1,670	742	629	1,371

Table 2. Water *used (mm)* for *land* preparation and crop growth period *under* recommended management in the selected *locations* of the *Ganges-Kobadak* Project *(Phase I),* the *Aus* seasons, *1985-89.*

Location	1985			1986			1987			1988			1989		
	IR	RF	Total	IR	RF	Total	IR	RF	Total	IR	RF	Total	IR	RF	Total
	Land preparation														
T3/S4K		-		-	-	-	248	11	259	268	25	293	223	13	236
T9/S4K	222	08	230	215	30	245	260	07	267	225	61	286	248	10	258
T3/S9K		-		-	-	-	226	19	245	208	03	211	230	00	230
T6/S9K	251	00	251	238	23	261	226	W	226	202	30	232	229	00	229
T10/S9K		-		-	-	-	181	63	244	199	19	218	-	-	-
T2/S11K		-		-	-	-	I23	105	228	I27	21	148	-	-	-
T6/S11K	227	36	263	207	46	253	167	58	225			-	203	00	203
Mean	233	15	248	220	33	253	204	38	242	116	26	231	227	05	232
Location	Growing season														
T3/S4K		-		-	-	-	744	453	1,197	792	961	1,753	794	738	1,532
59/S4K	721	496	1.217	762	708	1,470	708	504	1,212	602	1,110	1,712	670	737	1,407
T3/S9K						677	604	1,281	387	1,190	1,577	529	678	1,207	
T6/S9K	772	509	1.281	600	596	1,196	602	582	1,184	372	1,211	1.583	600	640	1,240
T10/S9K		-		-	-	-	624	628	1,252	367	1,142	1,509	-	-	-
T2/S11K		-		-	-	-	612	609	1,221	540	998	1,538	760	350	1,110
T6/S11K	992	379	1.371	906	603	1,509	420	802	1.222	-	-	-	-	-	
Mean	828	461	1,289	756	636	1.392	627	597	1,224	510	1,102	1,612	671	629	1,300

Table 3. Water *used (mm) by farmers for* land preparation and *crop growth period in* the selected *locations of the Ganges-Kobadak* Project (*Phase I*), the *Aman seasons, 1985-89.*

Location	1985			1986			1987			1988			1989		
	IR	RF	Total	IR	RF	Total	IR	RF	otal	IR	RF	Total	IR	RQ	Tota
T3/S4K							185	05	19(	00	120	120	244	19	263
T9/S4K	236	29	265	203	21	224	167	00	167	00	112	112	271	28	299
T18/S4K							-	-		00	133	133	-	-	
T3/S9K							233	20	253	198	34	232	230	06	236
T6/S9K	117	52	169	50	12(	170	23	215	231	210	37	247	234	09	243
T10/S9K							149	102	251	204	20	224	208	15	223
T2/S11K							00	241	241	177	56	233	180	25	205
T6/S11K	137	22	159	237	40	277	00	243	243	140	79	219	199	12	211
T10/S11K							00	24(	243	168	47	215	212	03	215
Mean	163	34	197	163	60	223	95	133	221	122	71	193	222	15	237
Location	Growing season														
T3/S4K							811	184	995	857	288	1,145	1,246	302	1,548
T9/S4K	1,013	234	1,247	538	1,053	1,591	-	-	-	900	600	1,500	996	345	1,34
T18/S4K							709	307	1,016	902	561	1,463	-	-	-
T3/S9K							633	670	1,303	686	629	1,315	770	402	1,17
T6/S9K	873	499	1,372	633	1,052	1,685	503	789	1,292	610	671	1,281	768	353	1,12
T10/S9K							515	694	1,209	675	563	1,238	748	375	1,12
T2/S11K							336	710	1,046	737	411	1,148	662	493	1,15
T6/S11K	2,054	291	2,345	791	1,052	1,843	339	910	1,249	635	488	1,123	777	349	1,12
T10/S11K							265	586	851	755	350	1,105	707	408	1,11
Mean	1,313	341	1,654	654	1,052	1,706	514	606	1,102	751	507	1,258	834	378	1,21

Table 4. Water used (mm) for land preparation and crop growth period under recommended management in theselected locations of the Ganges-Kobadak Project (Phase I), the Aman seasons, 1984-89.

Location	1985			1986			1987			1988			1989		
	IR	RF	Total	IR	RF	Total	IR	RF	Total	IR	RF	Total	IR	RF	Total
T3/S4K							89	05	94	00	120	120	231	19	250
T9/S4K	213	45	258	175	21	196	-	-		00	112	112	250	28	278
T18/S4K							-	-		00	133	133	-	-	
T3/S9K							206	20	226	208	17	225	224	00	224
T6/S9K	117	52	169	50	120	170	19	215	234	204	19	223	224	09	233
T10/S9K							138	102	240	187	20	207	203	03	206
T2/S11K							00	241	241	170	56	226	168	25	193
T6/S11K	195	22	217	220	28	248	00	243	243	136	79	215	182	12	194
T10/S11K						00	240	240	168	36	204	196	03	199	215
Mean	175	40	215	148	56	204	66	152	217	119	66	185	210	12	222
Location															
T3/S4K							796	184	980	776	288	1,064	1,02(	302	1.322
T9/S4K	936	258	1,194	497	1,053	1,550	688	209	897	722	600	1,322	859	345	1.204
T18/S4K							612	307	919	644	561	1,205	-		
T3/S9K							604	670	1,274	633	675	1,308	704	408	1,112
T6/S9K	839	499	1.33	527	1,065	1,592	462	789	1,251	553	689	1.242	730	362	1,092
T10/S9K							480	694	1,174	641	563	1,204	697	385	1.082
T2/S11K							304	710	1,014	733	411	1,144	657	493	1,150
T6/S11K	1,070	291	1.36	696	1,038	1,734	314	910	1,224	624	488	1,112	771	349	1.120
T10/S11K							232	666	898	672	418	1,090	702	408	1.110
Mean	948	349	129	573	1,052	1,625	499	571	1,070	666	521	1,188	767	382	1,149

Table 5. Average field level water use efficiency in the Ganges-Kobadak Project (Phase I), the Aus and Aman seasons, 1985-1989.

		Aus season		Aman season		
	applied	Water required (mm)	Water use efficiency %	Water applied (mm)	Water required (mm)	Water use efficiency %
	1,632	1.126	69	1,511	1,022	68
		1,190	59	1,975	1,082	55
	3,111	1.122	36	1.783	1,783	69
	1,726	1,083	63	1,356	1,141	84
1989	1,728	1.037	60	948	1,035	100
Mean		1,112	54	1.522	1.101	72

and 2.51 kg/ha-mm for research and farmers' management, respectively. The corresponding figures for Aman were 3.75 and 3.17 kg/ha-mm (Tables 6, 7, 8 & 9).

Table 6. Water use, yield and productivity of water under recommended management level in the selected tertiaries of the Ganges-Kobadak Project (Phase 1), the Aus seasons, 1985-89.

Location	1985			1986			1987			1988			1989		
	Water used (mm)	Yield (kg/ha	Water productivity (kg/ha-mm)	Water used (mm)	Yield (kg/ha	Water productivity (kg/ha-mm)	Water used (mm)	Yield (kg/ha	Water productivity (kg/ha-mm)	Water used (mm)	Yield (kg/ha	Water productivity (kg/ha-mm)	Water used (mm)	Yield (kg/ha	Water productivity (kg/ha-mm)
T3/S4	1,859	5,167	2.78	-	-	-	1,556	5,010	3.22	2,046	4,640	2.27	1,768	5,220	2.95
T9/S4	1,938	5,267	2.72	1,715	3,910	2.66	1,479	3,910	2.64	1,998	4,160	2.08	1,665	5,110	3.01
T3/S9	-	-	-	-	-	-	1,526	5,210	3.41	1,788	5,050	2.82	1,437	4,950	3.44
T6/S9	1,922	5.057	2.63	1,459	5,170	3.82	1,410	4,930	3.50	1,815	3,920	2.16	1,469	4,630	3.15
T10/S	2,109	3,697	1.75	-	-	-	1,496	3,840	2.57	1,727	4,620	2.68	-	-	-
T2/S1	-	-	-	-	-	-	1,449	5,050	3.49	1,686	5,050	3.00	1,313	4,920	3.75
T6/S1	2,830	4,127	1.46	1,762	4,890	3.27	1,447	4,280	2.96	-	-	-	-	-	-
Mean	2,132	4,663	2.27	1,645	4,610	3.17	1,466	4,600	3.14	1,843	4,750	2.48	1,532	4,966	3,26

Table 7. Water use, yield and productivity of water under recommended management level in the selected tertiaries of the Ganges-Kobadak Project (Phase I), the Aman seasons, 1984-89.

Location	1985			1986			1987			1988			1989		
	Water used (mm)	Yield (kg/ha)	Water productivity (kg/ha-mm)	Water used (mm)	Yield (kg/ha)	Water productivity (kg/ha-mm)	Water used (mm)	Yield (kg/ha)	Water productivity (kg/ha-mm)	Water used (mm)	Yield (kg/ha)	Water productivity (kg/ha-mm)	Water used (mm)	Yield (kg/ha)	Water productivity (kg/ha-mm)
T3/S4	1,851	4,953	2.68	-	-	-	1,074	4,980	4.64	1,184	5,730	4.84	1,572	5,640	3.59
T9/S4	1,767	5,403	3.06	1,746	5,033	2.88	897	4,400	4.91	1,434	4,767	3.32	1,482	4,450	3.00
T18/S	1,757	6,823	3.88	-	-	-	919	6,570	7.15	1,338	6,610	4.94	-	-	-
T3/S9	-	-	-	-	-	-	1,500	5,710	3.8	1,533	4,855	3.17	1,336	5,640	4.22
T6/S9	1,452	5,787	3.99	1,762	6,320	3.59	1,485	5,220	3.52	1,465	5,340	3.64	1,325	6,010	4.54
T10/S	1,290	6,213	4.82	-	-	-	1,414	6,040	4.27	1,411	5,970	4.23	1,288	5,220	4.05
T2/S1	-	-	-	-	-	-	1,255	5,440	4.33	1,370	5,555	4.05	1,343	5,963	4.44
T6/S1	1,692	6,287	3.72	1,982	3,897	1.97	1,467	5,600	3.82	1,327	5,405	4.07	1,314	6,080	4.63
T10/S	6,220	4.02	-	-	-	1,156	4,510	3.90	1,294	4,900	3.79	1,309	5,260	4.02	
Mean	1,622	5,955	3.74	1,830	5,090	2.78	1,289	5,390	4.18	1,370	5,459	4.00	1,371	5,533	4.06

Table 8. Water use, yield and productivity of water under farmers' management level in the selected tertiaries of the Ganges-Kobadak Project (Phase I), the Aus seasons, 1986-89.

Location	1986			1987			1988			1989		
	Water used (mm)	Yield (kg/ha)	Water productivity (kg/ha-mm)	Water used (mm)	Yield (kg/ha)	Water productivity (kg/ha-mm)	Water used (mm)	Yield (kg/ha)	Water productivity (kg/ha-mm)	Water used (mm)	Yield (kg/ha)	Water productivity (kg/ha-mm)
T3/S4K	-	-	-	1,615	4,810	2.98	2,090	4,270	2.04	1,812	4,920	2.72
T9/S4K	1,804	3,910	2.17	1,629	3,660	2.25	2,152	3,610	1.68	1,864	3,380	1.81
T3/S9K	-	-	-	1,564	4,880	3.12	1,891	4,920	2.60	1,519	4,730	3.11
T6/S9K	1,650	5,170	3.13	1,530	4,590	3.00	1,867	3,310	1.77	1,532	4,270	2.79
T10/S9	-	-	-	1,547	3,610	2.33	1,779	4,400	2.47	-	-	-
T2/S11	-	-	-	1,471	4,040	2.75	1,704	3,450	2.02	1,344	4,800	3.57
T6/S11	2,182	4,890	2.24	1,520	3,710	2.44	-	-	-	-	-	-
Mean	1,879	4,610	2.45	1,554	4,180	2.69	1,913	3,900	2.09	1,615	4,420	2.80

Table 9. Water use, yield and productivity of water under farmers' management level in the selected tertiaries of the Ganges-Kobndak Project (Phase I), the Aman seasons, 1986-89.

Location	1986			1987		1988				1989		
	Water used (mm)	Yield (kg/ha)	Water productivity (kg/ha-mm)	Water used (mm)	Yield (kg/ha)	Water productivity kg/ha-mm)	Water used (mm)	Yield kg/ha)	Water productivity (kg/ha mm)	Water used (mm)	Yield kg/ha)	Water productivity (kg/ha mm)
'3/S4K		-	-	1,185	4,750	4.00	1,265	5,320	4.21	1,811	5,480	3.03
'9/S4K	1,815	4,333	2.39	-		-	1,612	4,187	2.60	1,640	4,190	2.55
T18/S4	-	-	-	1,016	6,030	5.90	1,596	5,970	3.74		-	-
'3/S9K	-	-	-	1,552	5,000	3.22	1,547	4,560	2.95	1,408	5,190	3.69
'6/S9K	1,855	5,850	3.15	1,526	4,400	2.88	1,528	5,055	3.31	1.364	5,650	4.14
'T10/S	-	-	1,460	5,380	3.68	1,462	5,590	3.82	1,346	4.470	3.32	
T2/S11	-	-	-	1,287	4.140	3.22	1,381	5,050	3.66	1.360	4,937	3.63
T6/S11	2,120	3,150	1.49	1,492	4.980	3.34	1,342	4,820	3.59	1.337	5,720	4.28
T10/S1	-	-	1,191	4,060	3.41	1,320	4,020	3.05	1,330	4.120	3.10	
Mean	1,930	4,440	2.30	1,360	4,750	3.49	1,451	4,952	3.41	1,450	4,970	3.47

Water Adequacy

Clearly, farmers are growing rice in both the Ausand Amanseasons withlesswater supply thanrequiredformaintainingcontinousstandmgwaterinthefield.While all known research indicates that continuousshallow ponding is needed to obtain maximum rice yield, it is not clear yet how much yield reduction is actually taking place in farmers' fields which is attributable to the water shortage induced by the rotational method of water distribution. Analysis of some field-level water-status records indicates that the perched water table fluctuates between a level above soil surface to about 30 cm below for most of the days in the Aman season. Field water level, measured in PVC pipes installed at 50 farmer plots in each selected tertiary/ tubewell, dropped below 50-cm depth from thesoilsurfaceduringabout 10 percent of the Aman crop growth period. In the Aus season, field water table fluctuated between a level above the soil surface to about 45 cm below it during most of the season. In certain areas, the water table was found to drop below 80 cm on some days before irrigation water delivery was made. An in-depth study of the field water table fluctuations and their relationship to rice yields showed that yield reduction was not significant due to fluctuation of the water table (Ghani.1987).

Fertilizer Use and Rice Yield

Fertilizer (NPK) applied and rice yield obtained at the head, middle and tail reaches of the Kushtia main canal are presented in Table 10.

Fertilizer use decreased from head- to tail-end areas of the main canal. Rice yields obtained from head reaches were higher than those from tail reaches. Differences in rice yields from head to the tail ends of the main canal were higher in the Aus season than in the Aman season. Farmers generally used more fertilizer in Aman than in Aus. Higher fertilizer use in the *Aman* season may have been due to adequate and relatively assured water supply from the beginning of the crop season. However, farmers in the study areas applied relatively higher amounts of fertilizer N than the recommended rate in the Aman season.

Farmers along the head tertiaries generally applied higher amounts of fertilizer and obtained higher rice yields than those in the tail-end areas. The tertiary T9/S4K (middle) is an exception where the average fertilizer use rate was much lower in the head section, even though rice yield was higher. Uncertain and scanty water supply in the Aus season at the tail ends of secondary canals may have been the major reasons for low fertilizer use.

Table 10. *Average* yield and *input* used in the selected *tertiares of the Ganges-Kobadak Project (phase I)*, the Aus and Aman Seasons, 1982-89.

	Yield (kg/ha)		Nitrogen (kg/ha)		Phophorus (kg/ha)		Potassium (kg/ha)	
	Aus	Aman	Aus	Aman	Aus	Aman	Aus	Aman
T3/S4K	4.299	4.422	78	76	41	37	26	20
T9/S4K	3,721	4,167	118	115	47		31	31
T18/S4K	2.681	4.390	54	113	17	28	7	18
T3/S9K	4.290	4.592	101	106	47	46	30	28
T6/S9K	3,324	4.196	75	105	34	39	21	23
T10/S9K	3.134	4,614	54	86	27	46	14	28
T2/S11K	3,059	4.4%	59	83	33	48	20	28
T6/S11K	2.159	4.140	44	83	20		11	29
T10/S11K1,815	3.219	18	76	9	40	3	22	
Mean	3,240	4,250	67	94	31	41	18	25

Fertilizer N Efficiency

Fertilizer use efficiency is the output of any crop per unit of fertilizer applied under a set of environmental conditions. Though fertilizers N, P and K were applied, only fertilizer N was considered for calculation of its efficiency. This is because N is the most important nutrient for rice production and its deficiency occurs almost everywhere (Yoshida 1981). Rice responds better to the application of fertilizer N than to the application of P and K. Several factors determine fertilizer N efficiency for rice at the farm level (De Datta 1981). Among them are soil, rice variety, season, time of planting, water management, weed control, fertilizer source, time of application, pest control, and cropping sequence. Fertilizer N application under Recommended Management (R.M.) was fixed at 80 kg/ha but under Farmers' Management (F.M.) it varied from farmer to farmer. Mean rice yields in the Aus season of all tertiaries under R.M. and F.M. levels were 5,497 and 3,590 kg/ha, respectively (Table 11). So, there was a yield gap of 1,007.5 kg/ha between R.M. and F.M. levels. Farmers at the head and middle tertiaries (T3/S4K, T9/S4K, T3/S9K and T6/S9k) of the S4K and S9K applied relatively higher amounts of fertilizer N than those of the other tertiaries. However, average N use at F.M. level was 62.1 kg/ha. Average fertilizer N efficiency was 57.5 and 62.2 (kg rice/kg N applied) under R.M. and F.M. levels, respectively during the Aus season. Fertilizer use efficiency in the Aus season at F.M. level was higher than that at R.M. level. Barber (1977) and De Datta (1981) reported that fertilizer efficiency was high with the first increment of fertilizer at a relatively low rate. High fertilizer N efficiency with relatively low rates of fertilizer N application in tertiaries T18/S4K, T10/S9K, T2/S11K and T6/S11K during the Aus season under Farmers' Management level was consistent with literature.

Farmers generally applied a higher rate of fertilizer N in all tertiaries than that under R.M. level during Aman. Mean fertilizer N application during Aman under F.M. level was 98.0 kg/ha as against 80 kg/ha under R.M. level. Average rice yields during the Aman season were 5,462 and 4,927 kg/ha under R.M. and F.M. levels, respectively. Approximately 536 kg/ha of additional rice were produced under R.M. level over that under F.M. level. Fertilizer N efficiency under R.M. and F.M. levels was 68 and 51, respectively. Mean fertilizer N efficiency under R.M. was higher than that under F.M. level. The low fertilizer efficiency under FM. level during the Aman season may be attributed to relatively high rates of fertilizer N application. Results obtained on fertilizer N efficiency during the Aman season were also consistent with literature (Barber 1977; De Datta 1981).

Water Fertilizer Interaction

Field experiments were conducted in the G.K. Project area during Aman 1988 and Aus and Aman 1989 to determine a suitable time of fertilizer N and irrigation water application. Fertilizer and water management treatments were: fertilizer N application one day before irrigation (T1), fertilizer N application after completion

Table 11. **Fertilizer N use, rice yield and *efficiency of fertilizer* N use under recommended *(R.M.)* and farmers' management *(F.M)* practices *at* the selected *locations* of the *Ganges-Kobadak* Project (Phase *I*), the *Aus* and *Aman seasons, 1987-1989.***

Location	R.M.			F.M.		
		Yield	N-efficiency	N	Yield	N.efficiency
	Aus season					
T3/S4K	80	5.030	62.9	75	4,670	62.3
T9/S4K	80	4,040	50.5	125	4,680	37.4
T3/S9K	80	5,070	63.4	102	4,840	47.5
T6/S9K	80	4,530	56.6	67	4,060	60.6
T10/S9K	80	4,230	52.9	32	2,007	62.7
T2/S11K	80	5 . m	62.5	44	4.130	93.9
T6/S11K	80	4.280	53.5	30	2.140	71.3
Mean	80	4,597.1	57.47	62.1	3,589.6	66.9
Location	Aman season					
T3/S4K	80	5,560	69.5	75	5.240	69.9
T9/S4K	80	4.630	57.9	134	4,160	31.0
T18/S4K	80	6,600	82.5	108	6,030	55.8
T3/S9K	80	5,270	65.8	99	4.830	48.8
T6/S9K	80	5.480	68.5	108	5,040	46.7
T10/S9K	80	5,740	71.7	I03	5,150	50.0
T2/S11K	80	5,520	69.0	87	4,750	54.6
T6/S11K	80	5,470	68.4	89	5,080	57.1
T10/S11K80	4.890	61.1	89	4,060	45.6	
Mean	80	5,462.2	68.27	98	4,926.67	51.05

of irrigation (T2) **and** fertilizer N application after completion of irrigation followed by **soil** incorporation on the following day (T3). Yield responses of MV rice to fertilizer N application at different times of irrigation are presented in Table **12.**

Fertilizer N application followed by soil incorporation (T3) produced the highest rice yield during the three seasons in both locations excepting Swastipur **(T3/S4k)**

area, where rice yields were statistically identical at all levels of treatment during the 1989 Aman season only. However, substantial increase in yield was recorded in all seasons under treatment T3. Additional yield obtained from T3 over the control (T1) ranged from 0.46 to 1.41 t/ha. Similarly, treatment T2 produced an additional yield of 0.21 to 0.90 t/ha over the control. Rice yield increased by 11 to 38 percent under T3 as compared to the control. On the other hand, treatment T2 resulted in a 5 - 29 percent additional yield over the control.

The low yield of rice obtained from the application of fertilizer N one day before application of irrigation water (T1) may be attributed to denitrification loss of N and washing out of N with surface run-off. On the other hand, fertilizer N application followed by soil incorporation (T3) may have minimized such loss of N, and therefore, yield was higher than that from other treatments. This suggests that in the rotational irrigation system, fertilizer N should be applied at the end of irrigation and should be incorporated for higher yield. Application of Zn and S at the rate of 10 and 20 kg/ha with NPK resulted in a higher yield than with NPK only.

bl 12. *Yield respones of MV rice to fertilizer N application at different times of irragtion in the Ganges-Kobaduak Project (Phase I), the Aus and Aman Seasons, 1988-1989.*

Treatments	Swastipur			Shailkupa		
	Additional yield (t/ha)	Percent yield oover TI	Mean increase over TI	Additional yield (t/ha)	Percent yield oover TI	Mean increase over TI
	Aman 1988					
TI	4.4c			3.7c		
T2	5.0b	0.65	14.94	4.5b	0.80	21.91
T3	5.5a	1.10	25.29	4.8a	1.19	32.60
			Aus 1889			
TI	3.4b			3.9b		
T2	4.3a	0.84	29.32	4.4b	0.42	10.65
T3	4.6a	1.14	33.43	5.5a	1.51	38.32
	Aman 1989					
TI	4.2			4.9b		
T2	4.5	0.21	4.95	5.8a	0.90	18.44
T3	4.1	0.46	10.84	6.3a	1.41	28.89

Numerical values followed by similar letters in columns do not vary significantly.

T1 = N fertilizer application one day before irrigation.
T2 = N fertilizer application after completion of irrigation.
T3 = N fertilizer application after completion of irrigation followed by soil incorporation on the following day.

Table 13. Average annual grain yield (t/ha) for selected cropping pattern in the Ganges-Kobadak Project (phase I), Bangladesh, 1982-1989.

Cropping pattern	Total yield under recommended management	Total yield under farmers' management
Wheat-BR1-BR4 [a]	11.41 (8.93 [b])	10.06 (7.63)
Wheat-BR1-BR11	11.80 (10.34)	10.41 (9.09)
Gram-BR3-BR11	11.77 (10.56)	9.94 *(8.8)*
Gram-BR1-BR10	11.81 (9.81)	10.44 (8.93)
Lentil-BR1-BR4	10.61 (9.88)	8.14 (7.76)
Kheshari-BR1-BR11	11.36 (10.15)	10.28 (9.23)
Dhaincha-BR3-BR10	10.26 (10.26)	8.53 (8.53)
Dhaincha-BR3-BR11	11.64 (11.64)	10.17 (10.17)
Sunhemp-BR1-BR11	11.65 (11.65)	9.25 (9.25)
Wheat-BR6-BR10	10.50(9.50)	9.24 (8.14)
Wheat-BR1-BR10	11.25 (10.30)	10.65 (9.40)
Gram-BR1-BR11	10.47(9.36)	9.54 (8.46)
Cowpea-BR1-BR11	11.51(9.99)	10.80 (9.56)
Kheshari-BR1-BR10	10.84(9.95)	9.52 (8.69)
Kheshari-BR1-BR4	10.85(9.78)	9.74 (8.72)
Kheshari-BR14-BR11	10.21 (9.56)	8.07 (7.57)
Average	11.12 (10.10)	9.63 (8.75)

a Crops grown in the Rabi (winter), Aus and Aman seasons, respectively, i.e., wheat is grown in Rabi, BR1 in Aus and BR4 in Aman.

b Figures in parentheses are the rice yields (t/ha) for the pattern.

Cropping Pattern

Cropping pattern trials were conducted in the project area during the years 1983 to 1989 under recommended and farmers' management of inputs, with a view to maximizing farmers' economic return from available land and water resources.

Some tested cropping patterns, along with yields obtained under recommended and farmers' management levels are presented in Table 13. It can be concluded that two H W rice and a legume or green manure crop may be the best combination for areas where water availability permits two rice crops annually. Such combination produced about 12 tons/ha grain yield in the experimental fields, out of which about 10 tom were obtained from the Aus and Aman harvests. These patterns yielded about one ton less under farmers' management than under recommended management. Replicated trials in farmers' fields of T10/S11K produced over 6.0 ton/ha when BR11 was grown after green manuring (Sesbania), which is higher than the two rice crops grown under inadequate water conditions in the tail-end tertiary area prior to 1984. It provided an alternative for the tail-end farmers to grow one assured HYV Aman rice by transplanting at the recommended time in place of two rice crops under delayed and inadequate water supply conditions.

Therefore, production of a suitable non-rice crop during the Aus season as an alternative to rice should be emphasized in the tail-end areas. (BRRI-BWDB-IRRI 1986).

Among all the Rabi crops grown within the G-K Project, kheshari occupies the maximum area. In the project area, farmers generally cultivate kheshari as a relay crop. It was observed that the majority of the farmers (about 80 percent) broadcasted kheshari seeds between November 15 and 30. Some farmers broadcast pregerminated kheshari seeds if the moisture is not sufficient in the rice field. Average yield varies from 190 to 1,180 kg/ha (Table 14) depending upon the soil moisture, weather and farmers' practices (some farmers used green kheshari plants as fodder).

Wheat was the second most popular Rabi crop in the G-K area before 1987-88 because there was an initiative to popularize rain-fed wheat within the project area. Some farmers adopted this cereal crop and usually cultivated in low pockets of the G-K Project.

In the G-K area, yield of wheat was 1,510-2,326 kg/ha under nonimgated conditions. At the very beginning of the on-farm research in 1981, trials were conducted with wheat in 1981-82 and 1982-83 Rabi seasons and average yields of about 1987 and 1,750 kg/ha under RM and FM levels were obtained (Table 14). About 13.5 percent higher yield of wheat was obtained under RM level which may be due to the higher amount of fertilizer used in RM plots. Wheat trials were discontinued after the 1982-83 Rabi season as rice-rice-wheat is not sustainable (Bhuiyan and Gwnasekera 1988) and after that farmers were discouraged to grow wheat in the Rabi season. Yet some farmers within the project area practice wheat cultivation in some low pockets where mostly local Aman rice is cultivated in the wet season.

Gram is another popular Rabi crop in the G-K Project area. The sowing and harvesting dates are almost similar to those of wheat. Most of the farmers broadcasted gram between mid-November through mid-December and harvested by the end of March. Average yield of gram varies considerably from year to year depending on the soil moisture and rainfall. Average yield of gram over the years 1983-84 through 1989-90 was about 1.0 t/ha without fertilizer (Table 14).

Tabl 14. eld (Kg/) of populara rabi crops in the selected tertiaries of the Ganges-Kobadak oject (Phase I), Rabi seasons, 1981-82 to 1989-90

Year	Kheshari		Gram		Wheat		Onion		Garlic		Lentil	
	RMa	FM	RM	FM	RM	FM	RM	FM	RM	FM	RM	FM
1981-82	-	-	-	-	2477	2390	-			-		-
1982-83	-	-	1930	1510	1497	1110	-			-	280	180
1983-84	1320	1180	1280	1020	-	-	-			-		-
1987-88	990	760	450	400	-	-	8210	8280		-		-
1988-89	650	500	2030	1820	-	-	6450	6340	1830	-		-
1989-90	200	190	600	560	-	-	7676	6986		-		-
Mean	790	658	1258	1082	1987	1750	7445	7205	1830	-	280	180
Ferti-	N				80	30	45	33			20	
lizer use	P				60	34	44	46			60	
(kg/ha)	K				40	19	29	30			40	

* RM = Recommended Management. FM = Farmers' Management.

Onion is the second most popular non-rice crop grown in the project area. Popularity of onion increased after the 1986-87 Rabi season, when demonstration with onion started under RM level in different locations of the project (Table 15). Onion is very sensitive to moisture stress and also to excess moisture levels. Under irrigated conditions, yield of onion may *go* up to 20 t/ha with proper fertilizer management (Mondal 1988). In comparison to that, yield of onion is much lower in the study area. It was observed that yield of onion varied from 6.3 to 8.3 t/ha. Fertilizer application level was very low and only about 50-60 percent of the farmers used fertilizer in growing onion, which may be the major cause for the lower yield. It is also indicated that the majority of the farmers used "cowdung" (about 10 t/ha) in their onion field.

About 1 to 3 percent of the farmers in the G-K area grew pea, oil seeds and lentil during the Rabi season (Table 15).

North Bangladesh Tubewell Project

Improvements in the use of HYV rice. As in the case of irrigation water use, emphasis was given by the project management and research group from the 1982 Aman season to increase the use of high-yielding rice varieties by farmers. The following specific activities underscored the effort in this direction: (a) identification of target fallow farms and those planted to Aus rice which are on time for HYV rice in the

Table 15. Adoption of different rabi crops in tke Ganges-Kobadak Project (Phase I), tke Rabi seasons. 1983-84 to 1989-90.

Year	Adoption of crops (percent)							
	Kheshari	Wheat	Gram	Onion	Pea	Lentil	Oil seeds	Total
1983-84	7.3	3.8	0.7	8.4	-	-	1.6	21.8
1984-85	27.8	11.1	5.3	8.2	0.9	-	0.7	54.0
1985-86	22.9	11.1	11.1	8.7	3.3	-	-	57.1
1986-87	9.1	13.6	19.8	8.4	4.2	1.1	-	56.2
1987-88	18.7	5.3	7.3	15.3	2.2	1.8	-	50.6
1988-89	21.0	3.3	16.0	6.9	4.7	-	2.4	54.3
1989-90	13.0	12.3	3.8	15.8	2.3	0.8	2.0	50.0
Mean	17.	8.6	9.1	10.2	2.9	1.2	1.7	41.9

succeeding season, (b) information drive to familiarize farmers with recommended high-yielding varieties which are suitable for transplanting in the early, middle or late Aman season; and (c) better supervision of irrigation facilities and greater field inspection by the irrigation project staff to solve technical irrigation problems and thereby creating confidence in the farmers' minds about the reliability of water supply.

In the 1988 Aman season, the use of HYV increased to 74 percent of total rice area in the pilot tubewells compared to 36 percent for the 1982 Aman season. However, the HYV rice hectarage grew by more than 70 percent during the one-year period in 1982-83. During the benchmark period, only about 15 percent of all rice planted used HYV, whereas in the subsequent Aman seasons, in addition to high increase in area grown to H W rice, the percentage of HYV to all rice grown increased highly and consistently (Table 16).

Cropping pattern trials during the years 1984, 1987, 1988, and 1989 indicate prospects of diversified crops in the project area (Table 17). Crop diversification should be an important strategy for effective utilization of tubewells.

In the project, wheat coverage during 1983-84 was 68 percent and gradually decreased in the following years (Table 18). In the North Bangladesh Tubewell Project deep tubewells are highly underutilized in the Rabi season. In was observed from a study that only 0.16 ha/lit/sec were irrigated in the Rabi season as against the potential of 0.65 ha/lit/sec for rice. The potential for non-rice crops might be higher than the above figure. The soil is sandy loam and with high potential for growing non-rice crops. The lower wheat coverage may be due to the high price of seed and fertilizer and the late harvest of Aman. The low market price of wheat as compared to that of rice also affected wheat coverage. Moreover, the project authority allowed farmers to grow rice instead of wheat which was not allowed

Table 16. Irrigated area and MV coverage in the selected pilot tubewells of the North Bangaladesh Tubewell Project, Thakurgaon, Aman seasons, 1982-89.

DTW N".	Irriga-ble area (ha)	Irrigated area (ha)								MV coverage (ha)						
		1982	1983	19Y	1985	1986	1987	1988	1989	1982	1983	1984	1985	1987	1988	1989
63	60	120	55.5	59.5	59.5	58.7	56.7	59.5	55.5	15.0	30.4	39.3	38.5	41.1	45.3	34.4
77	49	10 8	46.6	49.0	47.8	44.5	45 1	47.8	44.9	24.3	17.9	36.8	38.5	15.2	34.4	27.1
89	49	32.9	46 0	49.0	48.6	46.2	46.6	48.6	38.9	30.4	35.2	40.1	41.7	39.3	38.9	11.9
91	74	34.0	14.4	62.6	11.7	72.9	48.2	16.7	48.2	24.1	41.3	50.0	51.4	41.3	42.5	34.4
117	61	28.7	61 5	60.7	62.8	58.7	60.7	61 8	59.9	19.4	11.1	44.2	38.5	14.4	30.4	28.3
118	46	18 V	47.8	46.2	55.7	44.5	46.2	M.%	46.2	14.2	15.6	411	42 5	1 6	16,	1.1
I19	57	16.1	72.8	a/	a/	52.6	56.7	61.9	56.7	12.1	11.1	21.1	24.3	34.8	11.1	11.1
120	61	16.1	64.8	60.7	61.8	58 7	60.7	66.4	50.6	17.4	19.1	4 . f	466	14.5	40.5	12.1
125	55	50.6	51.4	55.5	55.1	58.8	55.5	91.1	607	8.1	17.0	30.4	31.6	16.8	44.5	42.5
126	48	41.3	46.6	47.8	47.4	50.6	47.8	46.6	18.7	25 1	39.1	45.3	45.3	296	40.5	44.5
138	50	48.6	50.2	50.5	43 3	41.1	50.0	83.4	84.3	24.3	19.6	4 . 1	54.8	25.1	32.5	48.1
142	49	16.0	48.2	62.8	48.6	46.1	49.0	73.3	60.7	10.1	23.1	38.5	34 4	36.8	40.5	54.7

a/ Tubewell was not operated due to sand and gravel pumping problem.

during the previous years. Therefore, fanners preferred to grow rice which is the main staple and the return from rice is higher than that from wheat. In can be observed from the Table that potato and mustard are gaining popularity. There is no technical problem in terms of irrigation water availability and drainage in this area for crop diversification.

Yield and input *use.* The levels of fertilizer use in the Rabi, Aus and Aman seasons were lower than the recommended rate (Table 19). Farmers used a lower rate of NPK fertilizers in the NBTP area than in the G-K area and obtained lower rice yields though water was not a limiting factor in the tubewell area.

Table 17. Average annual grain yield (t/ha) for the selected cropping pattern in the North Bangladesh Tubewell Project, Thakurgaon.

Year	DTW NO.	Cropping pattern	Yield (t/ha)	
1984	63	Sonalika-Sunhemp-BR11	8.08(5.28)	7.40(4.70)
		Sonalika-Millet-BR11	8.08(5.28)	7.40(4.70)
		Balaka-Mungbean-BRIO	8.48(5.28)	7.79(4.79)
		Pavon-Dhaincha-BR4	7.38(5.00)	6.27(3.77)
	118	Sonalika-Sunhemp-BR11	8.30(5.60)	8.33(5.43)
		Sonalika-Millet-BR11	9.30(5.60)	9.43(5.43)
		Balaka-Mungbean-BR10	8.07(5.80)	7.08(4.12)
		Pavon-Dhaincha-BR4	7.78(5.58)	6.45(4.45)
	126	Sonalika-Sunhemp-BR11	9.18(5.78)	8.78578)
		Balaka-Mungbean-BR10	8.00(5.00)	8.01(4.81)
		Pavon-Dhaincha-BR4	8.02(5.02)	7.04(4.64)
1987	I26	Sonalika-Purbachi-BR11	12.21(10.33)	11.09(9.21)
1988	89	Kanchan-Millet-BR11	8.34(5.52)	7.71(4.89)
	118	Kanchan-Sesame-BRI0	7.33(4.89)	5.30(3.96)
		Fallow-Purbachi-local rice	7.95(7.95)	7.40(7.40)
	120	Sonalika-Sesame-BR11	6.64(4.59)	5.20(3.IS)
	I26	Fallow-purbachi-BRI1	11.44(11.44)	10.89(10.89)
		Kanchan-Millet-Pajam	8.44(3.67)	7.21(3.67)
	142	Fallow-Purbachi-BRII	9.90(9.90)	8.83(8.83)
1989	89	Kanchan-Millet-BR11	10.02(6.91)	8.46(5.35)
	118	Kanchan-Sesame-BRI1	6.63(4.64)	6.39(4.40)
	126	Mustard-Fallow-BRI I	6.61(6.04)	5.66(5.09)

Note: Sonalika, Balaka, Pavon and **Kanchan are wheat varieties.**
BR stands for **rice** variety.

Table **18.** *Adoption of different Rabi crops in the North Bangladesh Tubewell Project, the Rabi season 1982-83 to 1989-90.*

Year	Adoption of crops (percent)			Total
	Wheat	Mustard	Potato	
1982-83	38.3	-		38.3
1983-84	68.3	-		68.3
1984-85	43.3	-		43.3
1985-86	33.3	-		33.3
1986-87	37.2	-		31.2
1987-88	23.0	-		23.0
1988-89	21.7	2.2		23.9
1989-90	29.2	0.8	3.8	33.8
Mean	36.8	1.5	3.8	40.6

Table 19. *Average yield and input use in the North Bangaladesh Tubewell Project, Thakurgaon, 1983 - 1989.*

Year	Rabi season				Aus season				Aman season			
	Wheat yield (kg/ha)	Nitrog (kg/ha)	Phospho rus (kg/ha)	otash g/ha	Ria (kg/ha)	itroge g/ha)	ospho-rus g/ha)	Potash (kg/ha)	Rice (kg/ha)	Nitroge (kg/ha)	iospho rus kg/ha)	otash g/ha)
1983	2,380	66	64	40	3,539	52	46	35	3,973	45	43	29
1984	1,860	44	55	31	1,785	31	24	16	1,655	36	39	24
1985	1,276	43	24	17	3,100	45	49	25	2,109	32	35	30
1986	2,496	49	48	28	3,608	44	36	23	2,012	33	33	24
1987	1,662	47	44	28	4,203	51	51	31	3,146	38	37	23
1988	1,394	60	50	30	3,932	79	51	32	2,309	43	42	26
1989	2,124	62	51	30	3.663	75	48	27	2,319	37	31	18
Mean	1,884	53	48	29	3,404	53	43	27	2,503	37	37	24

SUGGESTED STRATEGIES FOR IMPROVED WATER MANAGEMENT

Ganges-Kobadak Project

Adjustment in riceproduction schedules. In theexistingcondition, the Aus and Aman rice is transplanted mostly in the second half of April/May and August/ September, respectively. Transplanting of Aus rice should be completed in March which will allow for better use of available rain in June-Julyand for use of HYVs both in the Aus and Aman seasons, leading to more irrigation coverage and higher annual rice production.

Soil moisture utilization. Means to produce profitable legume crops using the residual moisture after the harvest of Aman rice should be accelerated to utilize the period between the end of Aman and the beginning of Aus in the project area.

North Bangladesh Tubewell Project

1. *Water delivery schedule.* Farmersprefera waterdeliveryschedule which will allocate and distribute water to different areas or blocks of the service area

in a fixed or predetermined schedule. Blockwise rotational schedule of water delivery will improve the water distribution system.

2. *Cropping plan.* The diversified cropping plan should be adopted for maximizing use of land and water resources. The cropping schedule should be adjusted so that Aman cultivation can take advantage of the maximum rainfall period.

3. *Communication.* Communication between the BWDB staff and the water **users** (farmers) should be strengthened which will help in improving the water delivery schedule in the project.

4. *Socioeconomic factors.* Timely input and credit support and assurance of fair price for the products will encourage farmers to adopt diversified cropping.

Acknowledgements

The authors' sincere thanks are extended to the staff members of the Bangladesh Rice Research Institute, the Bangladesh Water Development Board, the International Irrigation Management Institute and the International Rice Research Institute, and especially to the cooperating farmers of the study area. Sincere appreciation is extended to Mr. Md. Arifur Rahman and Mr. Md. Abdul Maleque for typing the manuscript.

References

Barber, S. A. 1977. Efficient fertilizer. Page 13-19 In Agronomic Research for Food. American Society of Agronomy Speaal Publication 26, Madison, Wisconsin, USA.

Bhuiyan, S. I. and K. Goonasekera. 1988. Rain water management for increasing production of rice and upland crops. Paper presented at the International Rice Research Conference on Component Technology for Rice Farming Systems, IRRI, Philippines.

BRRI-BWDB-IRRI, 1983. Applied research for increasing irrigation effectiveness and crop production; First Progress Report, BRRI, Bangladesh.

BRRI-BWDB-IRRI, 1986. Applied research for increasing irrigation effectiveness and crop production; Third Progress Report, BRRI, Bangladesh.

De Datta, S. K. 1981. Fertilizer management for rice. In Principles and Practices of Rice Production: 371411.

Ghani, M. A. 1987. Improved watermanagementforriceirrigationsystemsinunpublished Ph. D. thesis, USU, Logan, Utah, USA.

Mondal, M. K. 1988. Differential water management practices at the farm level for dry season crops in the Upper Talavera River Irrigation Systems. Unpublished M.Sc. thesis, University of the Philippines at Los Baños, Philippines.

Yoshida, S. 1981. Mineral nutrition of rice. In fundamentals of rice crop science, IRRI, Philippines: 152-156.