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IMPACT OF IRRIGATION, SALINITY AND CULTURAL PRACTICES ON WHEAT YIELDS

A study of Fordwah/Eastern Sadiqia area, Punjab - Pakistan

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ABSTRACT

Fourteen farms, representing farmers' diversity in Fordwah/Eastern Sadiqia irrigation system, were selected to establish a relationship between cultural practices and wheat yields obtained in Rabi 1994/1995, salinity, irrigation.

For that purpose, data regarding farmers' practices, in particular irrigation and salinity, had already been collected before the beginning of the Rabi season.

The study started at the plot level with the wheat harvest and the analysis of its components. A 2.68 T/ha average yield was obtained ranging from 1 to 5.2 T/ha. It was also found that from the booting stage to the flowering stage, wheat was the most sensitive to any accident.

Main factors which impacted on wheat yields where subsequently determined with a statistical package. On that basis, a production function expressing relative yield reduction for the critical stage as a function of the date of sowing, the seeds origins, the quantity of fertilizers and the soil texture was calculated. Salinity was doubtlessly an important factor, but relatively low levels in this area and too few data did not allow an insertion of this factor in the relationship.

Wheat is generally grown for self-consumption but surpluses provide a non-neglectable revenue to farmers. Farmers' practices in this area show undeniable signs of intense cultivation as:

- irrigation is always provided to crops whatever the canal delivery is;

- inputs are always used. Fertilizers are given at least twice a season, even in smaller quantities, and for the wealthier farmers, treatment against salinity is ensured;

- equipment included tractor, rotavator, drill;

- the cropping intensity surpasses 100 percent sometimes and fallow is rarely used anymore.

But wheat suffers from the variability in water supply; and water efficiency is definitely low.

Moreover, absence of organic matter applications combined with salinity and sodicity (both mostly go together) impoverish soils. Even though salinity is not globally a serious problem in this area, at least in some cases, cropping pattern and rotations are fully determined by salinity, and farmer's liberty degree is almost hopeless. Those farmers facing an important hazard complete their productions with more or less important livestock used as potential revenue sources.

At the farm level, the study pushed further the understanding of farmers' practices related to wheat by studying their variability and the reasons determining the differences. The analysis revealed different wheat practices for similar objectives due to different strategies and specific constraints. Thus, five main sequences were identified and related to farmers' general objectives of subsistence and profit maximization: 1. intensification with tubewell water; 2. intensification with canal water; 3. intensification in labor; 4. extensification; 5. practices related to salinity. These various sequences help explain the yields obtained during this campaign.

TABLE OF CONTENTS

LIST OF TABLES AND GRAPHS

II. Literature review

III. Methodology

IV.1. Wheat Practices

IV.3. Wheat final yields

IV.4. Impact of external factors on yields

IV.5. Production function

ANNEXES

LIST OF UNITS

Area :	Weight :	Distance :	Volumes :
2.47 acres = 1 hectare	1 trollee = 80 maunds	1 foot = 33 cm	1 $foot^3$ = 23.32 liters
1 square = 25 kilas	1 maund = 40 kg	1 foot = 12 inches	1 mm = 10 m^3/ha
1 kila <= 1 acre	1 Ton = 10 Qx/ha	1 inch = 2.5 cm	
1 kila = 8 kanals	10 Qx/ha = 10	1 m = 3.28 feet	
1 acre = 4047 m^2	maund/acre		

Miscellaneous	Discharges
1 knot = 44.5 km/day	1 cusec = 1 cubic foot/s
1 dS/m = 1 mmho/cm	1 m^3/s = 35.3 cusec
	1 cusec = 0.028 m^3/s
	1 m^3/s = 1000 l/s

I.INTRODUCTION

I.1. Irrigated agriculture in Pakistan

I.1.1. Climate and rainfall

Pakistan's climate is arid to semi-arid. The temperature in most cultivable areas allows for year-round cultivation. Annual precipitations over the Indus plain ranges from 150 mm to 500 mm, whereas annual evaporation varies from 1,250 mm to 2,800 mm. This makes crop production impossible without irrigation (Barral, 1994).

I.1.2. Agriculture and economy

The total cultivated area of Pakistan was 21 million hectares (26 percent of the total area) in 1988-89, where 16.2 Mha (77 percent of the cultivable area) were irrigated. Currently, irrigated agriculture accounts for about 90 percent of Pakistan's agricultural output (Barral, 1994).

The agricultural sector counts for 26 percent of the Gross Domestic Product of Pakistan and constitutes 80 percent of the export earnings of the country. Moreover, some crop like cotton and sugarcane play a role in the industrialization process and the general economic development of the country. While these impressive figures show the importance of the irrigation sector and its predominance in the economy of Pakistan, a close look at the performance of the sector in terms of efficiency of water use and agricultural productivity raises some real concerns. Yields of the main crops in Pakistan are among the lowest in the world (World Bank, 1988). As well, there is now a general recognition that the productivity of the main crops (except cotton) is decreasing, so that the production may not answer the demand in the years to come if the current state-of-affairs in the irrigation sector remains unchanged. The population in Pakistan will reach 150 million people by the end of this century and is likely to double within 50 years if present trends continue.

I.1.3. Importance of irrigation in Pakistan

The Indus basin irrigation system (14.2 Mha) covers the world's largest contiguous irrigated area. Irrigation water stems from two sources, canal water supplies that are diverted from the main rivers of Pakistan through a series of barrages and headworks, and groundwater supplies that are pumped through a series of public and private tubewells.

a/ Surface water supplies

The total design diversion capacity of the main canals is 128 billions cubic meters in a whole year. The total length of the link canal branches and distributaries is about 57,000 km (Barral, 1994). These canals are fed by the Indus and its tributaries, which have their sources in the Himalayan mountains and the Hindu Kush with a total catchment area of 400,000 km^2. The tributaries of the Indus flowing into Pakistan are the Jhelum, Chenab, Ravi and Sutlej rivers. Originating in Afghanistan, another major tributary is the Kabul River (Cf. annex 1).

Under the Indus Water Treaty (1960), while the flow of the three so-called eastern rivers have been allocated to India, Pakistan is entitled to all the water of the western rivers.

While irrigation departments are responsible in each province for the control of water supply at the canal, distributary (secondary) and watercourse (tertiary) levels, farmers control their own water distribution. Starting from the nearest farmer to the tertiary intake and progressing toward the tail of the watercourse, at 6:00 am on Saturday or Monday, with a 7-day period, water turns are allocated to landowners with a duration proportional to the farmer's cultivable area. If one farmer has different parts in the command area he can have two or more turns. Numerous modifications of schedules occur in the form of water trading, mainly via lending or borrowing and, to a lesser extent, selling or buying.

b/ Groundwater supplies

In the last 30 years, extensive public development of groundwater resources has taken place through large scale vertical drainage schemes, entailing the installation of about 20,000 public tubewells in the Punjab, and through the even more recent development of groundwater exploitation by more than 300,000 private tubewells. The contribution of groundwater to the total water supply in the Punjab is estimated at 40 percent to 50 percent (Kuper, 1993).

I.1.4. Problems faced by the system

a/ Inequity in water distribution

Various studies have shown that water supplies are no longer distributed equitably, the original intention at the conception of the Indus Basin irrigation system (e.g. Kuper et al. 1994). Increased cropping intensities prompt farmers to seek water in addition to the sanctioned amounts, taking away water from other farmers.

b/ Variability in water supplies

The nature of the system (run-of-the-river supplies) and frequent interventions of operating staff, have resulted in frequent perturbations in the water supply (Kuper et al., 1994). Farmers are not sure if they will get water, while the discharge they receive is highly variable, impacting on agricultural production (Strosser and Rieu, 1994).

c/ Waterlogging

The increase in the diversion of river flows for irrigation, seepage from the canal, watercourses and irrigated areas, together with a flat topography and the lack of well-defined natural drainage in the Indus Plain resulted in a gradual rise of the groundwater table and increased waterlogging problems. Installation of public tubewells in the 1960's and more recently the rapid development of private tubewells have contributed to a decline in water-tables in large areas of the Punjab.

d/ Salinity

Even if irrigated with relatively good quality water, repeated irrigations and the rise in the water-table in addition to ancient salinity contribute to soil salinity in the Indus Basin. Another threat is posed by the increased use of low quality tubewell water. About 8 percent of the GCA is severely salt affected (Barral, 1994). Also a lot of area suffers from patchy salinity. Salinity and sodicity often go together, especially in the Punjab.

I.2. Institutional context and background of the study

IIMI was asked in 1989 by the Secretaries of Irrigation & Power and Agriculture of the Government of Punjab to commence work in the Fordwah/Eastern Sadiqia area, given the fact that a number of development projects would be initiated in the area. The objective of IIMI's research is to develop and pilot alternative irrigation management practices to optimize agricultural production and mitigate problems of salinity/sodicity in collaboration with national research and line agencies. The research is carried out at various levels of the irrigation system, from main system operations/maintenance (main canal, distributary) to watercourse allocation and farm/field level irrigation practices of farmers (Cf. annex 2).

The main system component of the research is carried out in collaboration with the Punjab Irrigation & Power Department and aims to develop tools to assist irrigation managers to make better decisions on operations and maintenance (IIMI, 1995). This is complemented by parallel research work concerning the impact of water markets on the quality of irrigation services and agricultural production and research on the impact of irrigation practices of farmers on soil salinity.

The present study was undertaken to strengthen the links between irrigation practices, soil salinity/sodicity and yields. In a first step wheat, the main crop in the winter irrigation season (rabi), was studied. It contributes to the farming system analysis with objectives to show how production choices are influenced by water supply characteristics on one hand, and to set up a simulation tool to assess farm water demand for irrigation purposes on the other hand (Rinaudo, 1994).

This report is the result of a five-month practical training undertaken in collaboration with the International Irrigation Management Institute, Pakistan, Cemagref, France, and the National Centre for Agricultural Studies in Tropical Zones (CNEARC), France.

I.3. Objectives and approach of the study

A double objective was assigned to this study. First, it aimed to estimate the impact of irrigation, salinity and cultural operations on wheat yields in the Fordwah/Eastern Sadiqia irrigated system. This study was undertaken at the *field level* which allowed accurate observations of the crop growth and irrigation practices and the determination of a straightforward relationship between the different studied variables and yield.

Secondly, this study attempted to understand farmers' practices and the conditions that determine them. Indeed, forced by specific constraints and depending on their objectives (and in particular to the objectives assigned to wheat production) farmers behave differently from each other, and have different production strategies. This part of the study focused on the *farm level* and on farmers' strategies regarding wheat and water allocation within the farm in different irrigation scenarios (quantity and quality of irrigation water).

a/ Approach of the study

For the first objective, this study used information obtained through IIMI's regular data collection, starting before Rabi and continued until the end of the season. In addition, two campaigns were organized: the first one to take crop cuts to determine yields for all sample fields, and the second one to make soil profiles to determine the root repartition/density, which is an important indicator of environmental conditions that were present during the wheat growth. Their extraction provided the linkage between soil, water, salinity and crop yields, and therefore helped to understand the hierarchy between factors having an impact on wheat yield (Soltner, 1993).

Statistical analysis was subsequently used to bring out the gist among all the data collected and establish a relationship between final yields and studied factors. Factors that were important in reducing the total yields were identified and marginalized by relating indicators of different yield components (indicative of stress that occurs in a particular stage of the crop) with farmers' practices. Finally, the wheat response to water, salinity, and cultural operations was formalized into a mathematical production function.

For the second objective, the study was undertaken at a farm level. Farms had been selected based on a farming systems analysis that group the farms in fairly homogeneous groups, a farm typology (Rinaudo, 1994). For each plot of each farm, the succession of operations was studied and compared to the rest of the fields in order to deduce general rules of practice. The next step was to understand the reasons for varying the average sequence and to make assertions on farmers' strategies. This was related back to the original typology, which provided additional socio-economic information to enhance the understanding of farmers' strategies. A better knowledge of all the crop production strategies within the farm would have helped the interpretation, but that was not possible.

Lastly, restitution was made to the farmers whose fields had been monitored. Discussions with individual farmers were necessary to check that the assumptions made concerning their strategies were correct, especially regarding wheat, and to better understand the way they manage their constraints. These discussions were important because presenting the research to farmers for their feedback clarified understanding of the farmers' perception. Although practices that could be changed to improve final yields were discussed with farmers, the purpose was not to make them change practices, but to discuss why they currently farm the way they do.

b/ Organisation of the report

After a presentation of the study area and a brief literature review on wheat yields and farmers' practices in general and more specifically in the Punjab, the choice of a methodology is set out in this report. In the fourth part, the report presents and discusses the practices observed in Fordwah/Sadiqia area. The different farmers' strategies regarding wheat production are subsequently mentioned and tested in different scenarios of water delivery. The yield levels resulting from the variety of farmers' practices are described and discussed in the next chapter. Main factors determining the final yields are stressed and selected to establish a production function.

I.4. Description of the research area

The research was conducted in eight sample watercourses in south-east Punjab, close to the town called Hasilpur. Four watercourses are situated on Azim distributary at RD 20, 43, 63 and 111, four are off-taking from Fordwah distributary at RD 14, 46, 62 and 130. The two distributaries are on the left bank of the Sutlej River, running more or less parallel to the river. They both receive their water from Fordwah branch, which in turn takes water from Fordwah Canal, starting from Suleimanki head on Sutlej River (see map). The head of the system is non-perennial and receives supplies from April 15th to October 15th only. However, some of the distributaries in the system, amongst other Fordwah distributary, receive water all year round (except for the month of January when canals are closed for annual maintenance). Azim is non-perennial disty, receiving water only in Kharif (V. Waijjen, 1991; IIMI, 1995).

I.5. Farming systems and selection of the sample farms

The first step of the farming system analysis presented in the introduction is the development of farm typology, i.e. the identification of distinct and homogeneous groups of farms regarding their characteristics, constraints, production strategies and participation in water transactions (Strosser & Rieu, 1994). This analysis was based on a socio-economic survey carried out for 278 farms located on two distributaries Azim and Fordwah.

This farm classification was carried out based on farm structure variables and production variables. The farm structure variables describe the permanent production factors (land holding size, canal and tubewell water supply, machinery, livestock). The production variables describe the cropping pattern and the performance of production (yields for the main crops, output per hectare). Eleven groups homogeneous in terms of production and water use strategies were identified (Rinaudo, 1994). The main characteristics of these groups are displayed in table 1.

Table 1. Main characteristics of farm groups (Rinaudo et al., 1995).

Farm strategy	Autoconsumption			Market orientation							
				Wheat-Cotton			Diversified cropping pattern				
		Intensive cult.	Extensive cult.	Tenants			Small landowners limited credit		Large landowners, mechanized		
Group No.	1	7	8	4	5	6	2	3	9	10	11
No. of farmers per group	53	24	15	12	35	30	22	19	28	28	12
Land holding (ha)	4.1	1.5	3.5	4.4	4.6	6.0	4.7	5.8	8.2	4.4	42.5
Land owned (ha)	2.3	1.3	2.5	1.5	1.3	1.5	2.1	2.6	5.9	3.5	15.8
Tractor owners (in percent)	9%	17%	20%	17%	11%	20%	5%	11%	50%	50%	92%
Yearly cropping intensity (in percent)	139 %	178%	122%	135 %	160 %	140 %	127 %	138 %	155 %	145 %	131 %
Gross Income (1000 Rs./ha)	3	33	15	5	13	17	5	18	26	15	26
Exchange of full & partial canal water turns (hour/ha)	1.5	5.4	2.3	4.2	1.0	1.0	3.3	7.6	1.3	0.3	7.0
Water purchase (hour/ha)	25.4	62.0	24.5	37.4	58.3	63.8	10.8	25.0	4.4	2.4	9.7
Water sale (hour/ha)	2.5	9.7	3.1	0.8	0.7	8.2	1.0	2.5	33.3	26.0	8.7

Three groups, Groups 9, 10 and 11, are composed mainly of large landholding farmers with a relatively good investment capacity, highlighted by the high level of mechanization and the presence of private tubewells. Groups 4, 5 and 6 are composed of tenants, characterized by a low percentage of tubewell owners. However, while Group 6 is characterized by small canal deliveries, Groups 4 and 5 receive relatively adequate canal supplies.

Groups 2 and 3 are localized upstream the irrigation system and receive a good canal water supply, which enables them to diversify the cropping pattern with sugarcane and rice.
Autoconsumption remains the principal objective of production activities for farms of Group 1, 7 and 8. Farms of Group 7, operating in a very small area (1.45 hectare on average) make a very intensive use of the land, and obtain among the best yields for cotton and wheat.
For farmers of Group 8, who receive remittances from family members working abroad, farming activities do not represent the only source of household cash income which explains that production remains extensive. Group 1 is mainly composed of small landowners, whose production activities are constrained by credit shortage. The objective of the production remains

autoconsumption.

The result of the farming system analysis provides a simplified description of the diversity of farmers' objectives and strategies that was used to select farms representative of this diversity, for which an in-depth analysis of wheat strategies and practices was carried out.

II. LITERATURE REVIEW

II.1. Wheat cycle and critical stages

There is much literature available on the different stages of wheat and the sensitivity of the crop with respect to water deficiency & soil salinity, Soltner (1993), Roberts (1993), Doorenbos (1992), Musick & Porter (1990), Kijne and Bhatti (1992), Schneider et al. (1969), Singh et al. (1987), Sebillotte et al.(1981). These data have been checked with the Agricultural Department's local office in the study area. Following their statements, length of crop stages were modified.

Table 2. Crop stages of wheat and sensitivity to water and salinity hazards.

Stages	Number of days	Events	Hazard	Effects
germination	7-10	from sowing to first leave	salinity + soil crust	- weak root development -low germination rate
tillering-crown root initiation	15-20	from first leave to third leaf	salinity + + + water stress + + +	- weak roots and shoots growth
Jointing	30-35	1 cm long spike and end of tillering		- lower density
Booting/ heading	15-20	from plant growing up to fecundation	water stress + + +	- spikes abortion
flowering	10-15	from flower apparition to grain growth	water stress + + +	- flower fading
grain filling	15-20	soft juicy grain (migration of the reserves from the stalks and leaves to the grains)	high temperature effect	- grains abortion
dough ripe	10-15	tough grain		
TOTAL	102-135	harvest		

Note : + to + + + indicates the growing importance of hazard.

The fact that water stress and soil salinity impact differently on wheat in the different stages of the wheat crop, allows a time-related diagnosis of the wheat yield and the factors explaining the gap between potential and actual yields. In the same sequence of the analysis, a number of indicators are proposed in the literature:

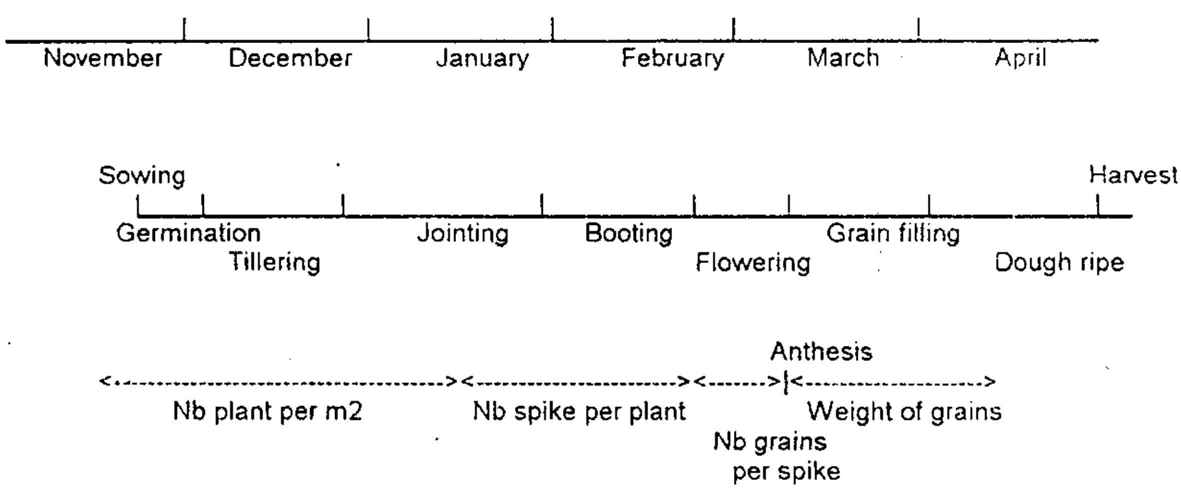
- the number of grains per spikes
- the number of spikes per plant
- the number of plants per m^2
- the weight of 1000 grains

However, according to Meynard & Sebillotte (1982) and Meynard et al. (1988), tendency is to consider only final number of grains per m^2, number of spikes per m^2 and weight of grains to recompose the final yield.

Thus, any stress during the sowing and tillering stage will affect plant density, i.e. number of spikes per m^2 and the potential number of grains per spike. From jointing stage to flowering stage, the total number of grains per m^2 will be reduced, i.e. the number of spikes per plant and the number of grain per spike.

Similarly, from flowering to dough ripe, the weight of grains will be affected.

Figure 1. Wheat cycle, critical stages and components elaboration.



This will be helpful for the study, because it means that yield components will give indications during which stress periods occurred.

II.2. Wheat roots

According to Mac Key, quoted in Musick & Porter (1990), average winter wheat roots reach 1.5 meter deep (only 1 m deep for spring wheat) because of their long growth period. In favorable conditions they can even develop to depths in excess of 3 m Kmoch et al.(1957) and Cholik et al.(1977) quoted in Musick & Porter (1990).

Seminal roots dominate rooting during the seedling stage. They have a higher order of branching than nodal roots. The seminal roots have a direct downward orientation and tend to have a linear distribution with depth.

Nodal roots develop from nodes in the crown in sequence as the main culm and tillers develop. Their growth starts about 25 to 30 days after plant emergence. Early deep development of the nodal root system is believed to contribute to the ability of the plant to deplete soil water from the lower profile (Schneider et al., 1963).

Therefore, by studying roots and soil profile we can understand why plants do not respond to water. Similarly, such an exercise gives information on adverse effects of water on the plant growth during the whole cycle or at the moment of the profile, but will not allow deduction of any particular accident in the past of the wheat. (An example of roots and soil interaction directly related to water will be found in annex 6.)

II.3. Some effects of irrigation and soil moisture stress on wheat yields

The literature generally describes the effects of quantity, quality and timing of irrigation on wheat yields.

II.3.1. Quantity

Water stress proved to be more detrimental to growth and other physiological processes than salt stresses (S.K. Sharma, 1993).

II.3.2. Quality

Groundwater (which is of lower quality than canal water) has now become a major source of irrigation in the Indus Basin representing 37 percent in Kharif season and 70 percent in Rabi season (Siddiq, 1994). Valles et al. (1989) recommend considering SAR and ECe of irrigation water with care because evaporation changes the chemical composition of water in the field. Furthermore, quality changes slightly during the season because of water-table depth variations. For these reasons, water analysis has to be considered very carefully. Furthermore, water quality does not directly affect crop yield (Hussain & Young, 1987, quoted in Siddiq, 1994).

Regarding the conjunctive use of water of canal water of good quality and tubewell of poorer quality, Hoffman et al. showed that blending saline and non-saline water was not desirable if the crop is sensitive and/or the saline water has a very high EC value. Indeed, portions of originally usable water can become useless by blending and flexibility can also be lost. Similarly, Boumans et al. (1988), quoted in Siddiq (1994), in a field survey found blending to be inferior to alternately using canal and saline water for cotton, but not for wheat.

Assessing the effects of salinity as a parameter of water quality depends on the soil, the crop, the water available, the irrigation system and the leaching rate (Pratt & Suarez, 1990).

II.3.3. Timing

Sharma et al. (1990), quoted in Siddiq (1994), carried out a two-year field experiment at Karnal in India to evaluate critical growth stages for irrigation scheduling of wheat *(Triticum Aestivum L.)*. Soil was sodic with sandy loam texture. When constrained to only three irrigations, the best is to irrigate at crown root initiation (30 days after sowing), tillering (50 days after sowing) and milk stage (108 days after sowing).

The crown (nodal) root initiation stage is the most critical stage in environment where significant water deficits can develop (Kijne & Bhatti, 1992, and Musick & Porter, 1990) and the water deficit are expressed through reduced vegetative growth (leaf area, tillers, dry matter accumulation).

Recommendations of the local office of the Agricultural Department in the study area were also noted. On average, five applications of 3 inches each were deemed necessary for wheat. This gives a total of 15*2.5*10*10 = 3750 m^3/ha i.e. 1500 m^3/acre, or 375 mm depth. It can go up to 2100 m3/acre with the rauni irrigation. The first application should be given 3 weeks after sowing, with recommended intervals of two weeks between each irrigation.

II.4. Wheat response to saline and sodic conditions

Salinity effects can roughly be classified in three categories:

(i) increased osmotic potential;
(ii) sodicity or clay dispersion and soil structure degradation;
(iii) toxicity due to ion concentration.

II.4.1. Increased osmotic potential

Increased osmotic potential corresponds to a high concentration of ions on the surface of the soil as a consequence of intense evaporation. This phenomenon occurs in arid areas where water-tables, too close to the surface, allow water to evaporate by capillarity and ions deposit. It is also frequent in soils that do not receive enough water to leach salts accumulated on the surface.

Soil is considered saline if the electric conductivity (EC) of a saturated extract oversteps 4 dS/m (1 dS/m = 1 mmohm/cm) or 40 meq/l at 25 °C (Doorenbos, 1992 and Lauchli & Epstein, 1990). If osmotic potential of the medium becomes lower than the plant's cells, the latter will suffer osmotic desiccation. Thus water quantities should be higher in saline condition. Nevertheless, Kuper and Van Waijjen (1993) advice giving it through smaller and more frequent irrigations.

According to Kriedmann (1986) and Papp et al. (1983), quoted in Lauchli & Epstein (1990), the early stages of shoots and leaves are relatively insensitive to drought and salinity but appear to be limited by the supply of assimilates. Leaf expansion is sensitive to drought and salinity.

II.4.2. Toxicity

A second effect of salinity is the forming of black to dark green areolas on the soil surface. It corresponds to an accumulation of magnesium ions, particularly on superficial horizons. These ions are very concentrated and penetrate the plant, creating ionic dis-functioning, especially as far as potash and calcium are concerned. This phenomena is toxic for the plant and can evolve toward sodicity (Lauchli & Epstein, 1990).

II.4.3. Sodicity

Sodicity corresponds to a destruction of the structure and the physical properties of the soil, especially the clay complex, by Sodium ions (Na+), creating clays dispersion (Valles et al., 1989). These soils are infertile on the surface because organic and clay particles, not kept anymore, sink lower with each irrigation. Porosity of these soils decreases strongly, impervious horizons take shape underneath and roots progressively suffocate (Soltner, 1993).

Sodicity is quantified by the exchangeable sodium percentage (ESP) and the Sodium Absorption Ratio (SAR) that indicates competition between ions $Ca2+$ or $Mg2+$ and $Na+$ to penetrate clay particles. When the SAR reaches 10, sodicity affects crops' growth. This value varies nevertheless with climate and natures of clays. According to Northcote & Skene (1972), quoted in Lauchli & Epstein (1990), soils whose ESP oversteps 6 mmohs are sodic, those whose ESP go past 15 mmohs are strongly sodic.

II.4.4. Sensitive stages

Most plants, including wheat, are more salt-sensitive during the vegetative growth (especially for the juvenile roots) than during germination (Maas, 1990 and Lauchli & Epstein, 1990), while reproductive stage stays in between. For D.R. Sharma et al. (1993) though, both first stages have the same sensitivity. Delane et al. (1982) and Weimberg et al. (1984), quoted in Lauchli & Epstein (1990) demonstrated that shoot growth is usually even more affected by salinity than root growth.

According to Kriedmann (1986) and Papp et al. (1983), quoted in Lauchli & Epstein (1990), the early formative stages of shoots and leaves are relatively insensitive to drought and salinity but appear to be limited by the supply of assimilates. Leaf expansion is sensitive to drought and salinity.

Salinity reduces grain yield by reducing the number of grains more than seed weight while straw yield is reduced by salt stress only during the vegetative stage (François et al., 1986 quoted in Siddiq, 1994). This result means that yield will not be reduced if proper pre-plant irrigations and careful management are used during germination and emergence of the seedling to leach salts out of the seed area and shallow soil depths (Javaid & Channa, 1990, and Ahmad & Rahim, 1990, quoted in Siddiq, 1994).

Sharma et al. (1993) report that wheat yield increased by 39 percent when irrigation at crown root initiation stage was substituted with canal water. Doorenbos (1992) and Maas (1984) report that ECe should not overpass 4 mmohs/cm during the germination stage. In the following stages, yield decreases up to 10 percent if ECe equals 7.4; 25 percent if ECe equals 9.5; 50 percent if ECe equals 13, and 100 percent if ECe equals 20 mmohs/cm. And Minhas (1993) and Sharma et al. (1990) in a two-year field experiment concluded that wheat grain yield was significantly higher when crop was irrigated at crown root initiation with canal water rather than sodic tubewell water.

II.4.5. Consequences

Most of the time, salinity affects wheat and plants both physically and chemically.

In saline soils, affected roots become shorter and thicker (Lauchli et Epstein, 1990). When suffering from desiccation due to high osmotic pressure, plants behave like in water stress conditions and yield will be reduced (Siddiq, 1994). After exposure to salinity, leaf growth reduces in plants because of water deficit. This response is very rapid and reversible (Sharma, 1993). However, osmotic stress imposed by saline solution is not the major factor threatening survival of wheat, contrarily to ion effects (Kingsbury et al., 1984, quoted in Siddiq, 1994).

In sodic soils, nutritional problems combined with physical condition of the soil result in growth and yield reduction.

Chloride concentration appears not to be toxic to wheat (Kingsbury & Epstein, 1986, quoted in Lauchli & Epstein, 1990) but prevents nitrogen absorption (Cramer et al., 1986, quoted in Lauchli & Epstein, 1990). Nitrogen deficiency affects the number of grains per m^2, i.e. the tillering stage and the number of grains per spike, but the weight of a thousand grains is scarcely affected. Just the opposite occurs: grain size tends to be bigger than normal.

Sodium concentration is toxic and can lead to calcium shortage which directly affects roots length (Cramer et al., 1986, quoted in Lauchli & Epstein, 1990, and Maas, 1990). These mineral deficiencies often result in aborted spikes on the top or at the bottom.

Maas and Hoffman (1977) showed that yield starts to decrease as soon as soil salinity overpasses a threshold of 6 dS/m for *Triticum aestivum*. Crop response to salinity can be represented by two linear lines, one a tolerant plateau with a slope zero and the other a concentration-dependent line whose slope (equal to 7.1 percent for wheat) indicates the yield reduction per unit increase in salinity. Dry matter yield is even reduced when salinity stays lower than this threshold found for grain production.

II.5. Importance of cultural practices on wheat growth

II.5.1. Sowing

According to Siddiq and Byerlee (1990), an average delay of seven days in planting may depress wheat yield up to 200 kg per hectare.

II.5.2. Soil preparation

The number of ploughing and the quantity of seeds proved to be significantly related to yields, accounting for about 30 percent of yield variations (Kuper & Van Waijjen, 1993).

II.5.3. Fertilization

According to Mass (1990), fertility primarily limits plant growth compared to salinity. As well, when salinity and soil infertility similarly limit yield, decreasing salinity and increasing fertility gives similar benefits. This point explains the considerable superiority of canal water, which transports a high quantity of sediments improving soil fertility, over tubewell waters. However, Bernstein et al. (1974), quoted in Siddiq, 1994, through experiments observed that when salinity was the limiting factor, increasing fertility would be relatively ineffective compared to decreasing salinity. Most studies indicate that excess applications of N, P, K do not affect or reduce salt tolerance, but in non-saline zones, farmers declare that overdoses improve yield (Siddiq 1994).

II.5.4. Diseases and mineral deficiencies

Some selected plant diseases that occur due to mineral deficiencies are given in the table on next page.

II.5.5. Other

Climate influences the wheat response to salinity as much as any other factor. Studies showed that when crops are grown at higher temperature, yields decrease more, but humidity does not seem to affect yields greatly (Maas, 1990).

Table 3. Plant diseases and mineral deficiencies (Taureau et al. 1989).

Phenomenon	Cause
rotten roots	pictin echaudage (opiobolus graminis)
dark brown spots on spikes, leaves and stalks	fusariose (fusarium spp.)
laying down spots	irregular spread of nitrogen
aborted spikes or dried up grains	high temperatures (end of booting) or high density
well-filled but small grains	water shortage
belated spots	copper shortage
irregular first growing	dryness when sowed
high weight of grains and low rate of grain per spike	shortage of nitrogen

III. METHODOLOGY

III.1. Sample selection

Information on structural and functional characteristics of all the farms (278) of the eight sample watercourses along the Azim and Fordwah distributaries were already available for the year 1993. This information had been used to analyze farming systems and to build a typology of farms. However, only 15 farms had been monitored for farming and irrigation practices (i.e soil preparation, date of sowing, input use, irrigation water supplies, timing and source of irrigation water, etc.) on wheat at the field level. Salinity, water quality and plant water stress had also been measured by laboratory analysis and tensiometer graphs for four fields belonging to four of the 15 farms.

Since these data were necessary to establish a relationship between farmers' practices, salinity, irrigation and wheat growth and development, it was decided to work on these 15 farms only, whatever their strategies regarding wheat. Eleven of these 15 farms were representative of the 11 groups presented in the introduction. And as the total number of samples fields had to be limited to 50 for practical analytical reasons (time required for collecting wheat yields, processing information, analyzing correlations, etc.), this choice of a limited number of farms was consistent with the need to work on a large number of wheat plots for each selected farm rather than on a few wheat plots of many farms in order to better understand farmers' decisions regarding irrigation water distribution within the farm.

Field activities for the present study started on April 22 as farmers had already harvested for a week. Depending on the fields already harvested by farmers, sample fields were selected for the study. One farm had to be dropped because all its plots already had been harvested by the start of the study. A total of 64 samples were eventually harvested. Four plots were selected for further investigation as information on salinity had been collected for several years and water quality and tensiometers readings were also available.

Figure 2. Selection of sample farms and sample fields.

Sample farms considered	choice justification
Farms on the 8 watercourses monitored for hydraulic, salinity and economic data (total 278 farms)	farms already classified in 11 groups according to physical and socio-economic variables
Farms mainly growing wheat and cotton extremes avoided	farmers' strategies related to wheat production contrasted yield levels and production targets (for sale or personal consumption)
One representative farm of each of the eleven groups + 4 farms (four plots) monitored separately for salinity information (total 15 farms)	available data concerning practices, inputs, water and salinity
One farm eliminated (14 farms left) 64 wheat plots harvested (samples) 6 root profiles analyzed	farmer's harvest schedules contrasted fields situations within a farm
56 samples	incomplete data

III.2. Limitation of the results

The generalization of the results obtained in this study are limited by the choice of the sample farms. In order to have a maximum representation of wheat yields in contrasted situations, we could have started the survey from four main groups of farms characterized by their wheat yields and salinity levels, such as good yield and high salinity, good yield and low salinity, bad yield and high salinity, bad yield and low salinity. At a later stage, the results of the analysis could have been correlated to strategies of the 11 farm groups already identified in order to reduce the number of groups. However, the data available did not allow us to proceed in that direction of analysis. Moreover, the sample farms monitored did not represent in fact all the groups of the typology. The following table, presenting the basic characteristics of the sample farms, shows that there are no farms representing Group 5 and Group 8, although Group 5 had one of the best average wheat yield (Rinaudo, 1994).

Table 4. Main characteristics of sample farms.

Farm Number	Group	WC	Waraban di turn	Total area (acres)	Area under wheat crop (acres)	percentage of wheat	Number of fields harvested	Salinity
191	3	A20	3	11	4.44	40%	6	no
208	6	A111	5	6.4	4.4	68.7%	2	some
210	10	A111	13	10.35	5.75	55.5%	4	yes
<u>213</u>	10	A111	14	12	1.5	12.5%	1	yes
<u>220</u>	11	A111	4	22	22	100%	3	yes
66	2	F14	5	3.3	2.75	83.3%	2	some
47	9	F46	35	18.5	11.75	63.5%	4	no
133	1	F62	12	12.75	5	39.2%	6	no
<u>136</u>	9	F62	13	10.5	7.5	71.4%	5	no
<u>140</u>	1	F62	18	2.75	1.5	54.5%	1	no
249	4	F130	22	9.25	7.75	7.75%	7	yes
267	7	F130	23	2.25	1.5	66.6%	2	no
275	11	F130	29	23	14.65	63.7%	8	no
277	9	F130	37	19.5	17.4	89.2%	10	no
TOTAL							61	

Note: Underlined farms are not representative of the 11 groups. For more information, see annex 3.

Table 5 shows the distribution of the sample farms among farmers' strategies regarding wheat.

Table 5. Sample farm distribution in the wheat strategy classes.

			Number of sample farms	Farm numbers
Good yields	high inputs level	high sale	4	275, 220, 249, 277
		no sale	0	
	low inputs level	high sale	0	
		no sale	1	267
Bad yields	high inputs level	high sale	1	213
		no sale	1	66
	low inputs level	high sale	3	208, 47, 136
		no sale	4	191, 133, 210, 140

Another limitation of the present study relates to the data available. Wheat growth was monitored only for four plots, which considerably limited the interpretation of the results obtained. Information concerning stress periods, plant evolution and plant stages apparition is missing, and this data gap made analyzing the effect of belated sowing more difficult.

Regarding irrigation data, the irrigation timing was given mostly for a group of fields, so that a first approximation consisted of distributing the total figure between all the concerned plots proportionately to their specific areas. The estimation of irrigation water quantities was not very accurate either (with an estimated error of 30 percent), but the data available did not allow for more accuracy. (For more details refer to annex 10 enclosing the list of available and missing data and details of calculations.) Moreover, soil salinity data and tubewell water quality were also missing for most of the plots and this information could not be included in the analysis.

A consequence is that, considering the importance of the irrigation parameter for the rest of the study and considering the number of approximations that were done about it, the calculations must be corrected as soon as missing data, that were estimated, are known. For now, results announced about the impact of surrounding factors on wheat yield variations can only be considered as hypothesis.

III.3. Methods and materials

III.3.1. Data collection procedure

Information regarding farming practices on wheat had already been collected by the field assistants since the end of the previous cotton season. It concerned the farmers' practices, i.e. the date of sowing, the soil preparation (number of ploughings, number of plankings and nature of the tool used), the input use (nature, date and quantity used), and the irrigation (nature, timing and date of each application). Salinity data (SAR, RSC, Ec and pH) and tensiometers diagrams were also available for four plots.

Activities undertaken as part of the training period concerned the harvest of wheat, the checking of some data (especially for the plots that were treated differently from one half to another), the collection of missing data (such as the cultural past of the plot), its status, the origin of the seeds, the depth of the soil preparation, the salinity treatment, the soil texture and structure, the roots aspect and the soil layers.

Table 6. List of information collected during the present training period.

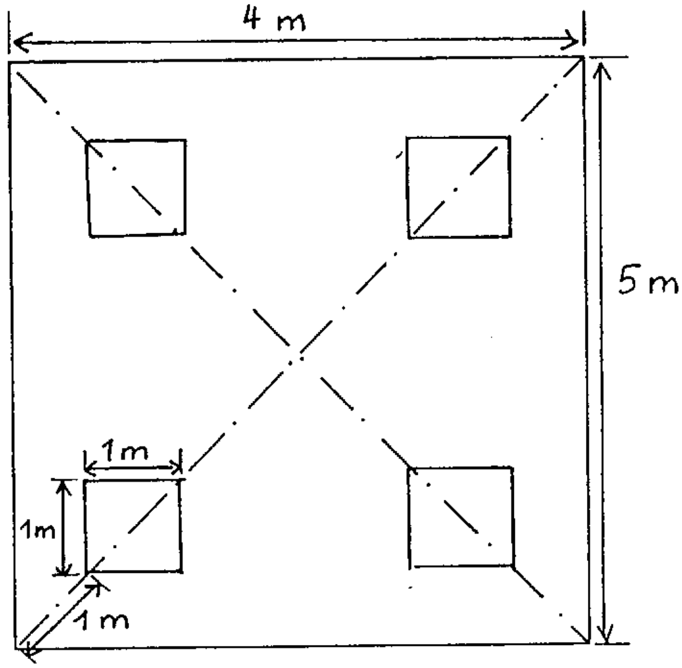
Observation sector	Type of Information	Level of observation	Remarks
field conditions	fertility, texture, structure, salinity, soil moisture, weeds, root profiles	sample field observations	
cultural practices	cultural past, dates and characteristics of each operation	farmers' interviews, agricultural department and field assistants' assessments	with Pakistani translator
surrounding conditions	rainfall, climate, mineral deficiencies	field observation, references	
wheat components	dry matter weight number of spikes per m^2 number of grains per spike weight of thousand grains	final results on wheat samples	manual counting the number of grains and the final yield were calculated

For more details refer to plot card in annex 4.

a/ Choice of sub-samples for harvesting

For each selected plot, a 20 m^2 frame was taken in a representative place of the field. It could be anywhere in a homogeneous field, as long as borders were avoided. In an irregular field, the sample location was chosen in such a way that spots were equally represented. On each diagonal, two square meters (total four) were harvested and kept in identified bags.

Figure 3. Harvesting procedure.



For each sample, a plot card was filled with information (farmer's name, plot number, watercourse, area, etc.), notes about the crop (homogeneity, special location, weeds, etc.), about soil (texture, salinity, etc.) and a drawing of the field and the sample location was made. In order to make these plot cards understandable to anyone, a card guide was made, which explains with accuracy the meaning of any comments written on these plot cards (See Plot Card user's guide in annex 5).

As our activities disturbed farmers during one of their busiest periods (wheat harvesting), they were given a financial compensation and seeds were returned to them at the end of the study.

b/ Soil-roots profile

A root profile is the ensemble constituted by the succession of soil beds, individualized by cultural tools, roots and actions of external natural factors (Soltner, 1993).

This was done in order to discover the different soil layers and to see, in a cultivated soil, the impact of the cultural practices on soil and underground life, especially the roots. Structure, texture, color, moisture, porosity, roots depth, health, shape, and fauna were observed.

The best scenario would have been to do one or two profiles for each sample plot. Time constraints made this impossible as some farmers had already ploughed their fields for the following crop once the wheat harvest finished. It was finally decided to profile the four fields that had been monitored with more details on salinity because they presented four contrasted situations of salinity and water supply: one using only its own tubewell water, one using only canal water, the third using both of them, and the last using neither canal water nor its own tubewell. Tensiometers readings were also available for these fields for the Rabi season.

Since wheat had already been harvested, we had no indication of the status of the crop itself. The profiles were dug anywhere far from the plot boundaries and not too far from the tensiometers. In two of the four cases, one profile only was made, because of the soil toughness and the difficulty to show up the roots.

For each sample a 60 cm deep square hole was dug in such a way to avoid destroying plant roots and so that a 50*50 cm^2 grid could be fixed against one of the vertical walls, as close as possible to the wheat plant. After using a knife, roots came out and a drawing was made (see roots profiles and comments in annex 6). For each 5*5 cm square unit of the grid, the number of roots was counted, whatever its thickness and even if the same root appeared many times in one square or if the root was a ramification. A five-unit scale was used according to the following principles:

(i) completely blank if no roots,
(ii) one line if one root,
(iii) three lines if two to four roots,
(iv) six lines if five to seven roots,
(v) crossed lines if eight to ten roots,
(vi) full black if more than ten roots.

Also, observations concerning soil colors, structure, horizons, compacity, organic matter presence and decomposition were quoted.

III.3.2. Statistical results analysis

Two types of analysis have been undertaken: first, between the final yield and its components in order to deduce which period had been most critical in this area so that it would give an orientation in the research of the most determinant factors having an impact on wheat yields; secondly, between the final yield and these external factors so that the most important ones could be selected in order to write a final production function.

A French statistical package (not commercialized yet) called Winstat was used in that purpose. Winstat allows two main treatment:

(i) statistical *description* of qualitative or quantitative variables taken one by one. Enrolment and percentage of the total population are given for the first ones, whereas average, standard deviation, minimum, maximum and median are given for the second ones.

(ii) statistical *treatment* called *correlation* for quantitative data, *cross table* for qualitative data, and *distribution* for qualitative data crossed with quantitative ones.

Average, standard deviation, Pearson coefficient (R) and percentage of error chances (P) are given for the quantitative data. This last coefficient (P) indicates significance of correlation between two variables. A high R value indicates strong association between the two variables. Conventionally, a value of P lower than 5 percent means that the relationship is significant in a statistical sense.

In cross tables, tests of Chi-square are done, while percentages of total population, columns and lines are given.

Graphic distributions for qualitative variables as well as linear regressions for quantitative ones can also be run, but no equation is calculated. For multi-variable analysis, another package named SPSS was used to complement Winstat.

Nevertheless, the total samples being quite few and results being very heterogeneous, traditional statistical treatments were not really appropriate to the data matrix analysis. Therefore, a big part of the analysis was done manually which privileged the agronomic interpretation. For instance, because farmers use relative valuations within their farm, it was almost impossible to establish for all the fields clear correlations between practices and general external factor, such as soil, fertilizers, etc. Though, it was sometimes obvious that farmers had the same strategies expressed somehow differently. A majority uses higher doses of urea in hard structure soils, but this does not show up with correlation analysis because the hardness threshold is different for all of them and scales of doses do not begin at the same level.

Winstat allowed finding which relationships exist between wheat, salinity, irrigation and cultural practices and selecting main factors that should be used in the following step of the study. Indeed, for practical application all factors must be reduced to a manageable number of major ones to allow meaningful analysis of crop response at the field level.

With each farm representing a group of farmers, the purpose was to understand the practices of each group, with the purpose to standardize it. In that context, using averages and percentages did not make sense. Nevertheless, in order to ease the reading of farms' main characteristics and deduce their specificities, general tendencies for practices during Rabi 1994/95 are given.

III.3.3. Water balance simulation and production functions

Crop-water production functions are mathematical expressions of the relationship between crop yield and the amount and adequacy of the applied water. Knowledge of crop response to water is an essential element in any water management assessment. But because irrigation waters contain dissolved salts, and because farmer practices are involved in plant response to water, salinity and cultural practices must be considered simultaneously with irrigation amounts.

The irrigation variable had to be represented in a more sophisticated way than only a quantity of water supplied, or a number of irrigation as done in many economic analyses of production functions relating water and yields or production. In fact, the variable selected is to combine the number of application and the amount of water applied for each application. A water balance simulation allows to integrate these two aspects in a single parameter (see graphs in IV.2 and annex 11)

The relative evapotranspiration deficit ETa/ETM - where ETa is the actual evapotranspiration (also represented by ETR) and ETM is the maximum evapotranspiration when crop water requirement is fully met by available water supply for the total plant cycle without any major constraints occurring during this cycle (also represented by ETcrop) - has been selected to integrate the different characteristics of the irrigation water supply and express the stress suffered by the wheat crop. This indicator can be calculated for the whole wheat cycle or for specific stages of the plant growth.

Depending on the level of stress, a yield reduction may occur that will be expressed by the ratio Ya/YM - where Ya represents the actual yield measured in the field (also represented by Y0) and YM is the maximum yield expected in the area under local conditions according to local research and extension institutes.

The software CROPWAT developed by the FAO (Doorenbos, 1992) was used to express the relative yield decrease (Ya/YM) as a function of the ratio ETa/ETM. This classical relationship was obtained through the following steps as recommended in Doorenbos (1992):

(i) determining maximum potential yield (YM) of adapted crop variety considering the main external factors. YM is always inferior or equal to the Ymax, the theoretical maximum yield in Punjab according to the local agricultural institutes; calculating the ratio Ya/YM;

(ii) calculating the relative evapotranspiration ratio ETa/ETM for the whole wheat cycle and for each growing stage;

(iii) representing the relative yield reduction Ya/YM as a function of the relative evapotranspiration deficit ETa/ETM;

Details of calculations as well as the justification of parameters' choice are explained in details in annex 10.

The final step of the analysis was the development of a linear production function integrating simultaneously the impact of irrigation water supplies and other farming practices on wheat yields. Other factors influencing wheat yields were added to the most significant relationship between Ya/YM and ETa/ETM and a production function was obtained using the statistical software SPSS.

III.4. Feedback to sample farmers

III.4.1. Materials and tools

Before starting any discussion, farmers' practices had to be presented to them, according to the way we understood them. For that, starting from the beginning of Rabi season to the harvest time, farmers' practices were recomposed step by step on a white board for each farm.

Colored cards representing given practices were used in the simplest and most significant drawing, always subtitled in Urdu: blue when related to rain or irrigation, pink for any input, yellow for any soil preparation. The Islamic calendar had to be used sometimes for local farmers do not divide time as Western farmers do.

In order to facilitate farmers' intervention and corrections, cards were simply put down on an horizontal board, where the farmers could move the cards. Indeed, the farmer's participation was essential and we noticed that using cards proved most efficient.

A map of the farm was also prepared for each restitution with farmers. This card was also a powerful tool to identify differences in farming practices related to location (zones with different salinity levels, fields with different tenure, variability in access to irrigation water resources, etc.).

III.4.2. Organizations of restitutions to sample farmers

The restitution of the results involved several IIMI researchers working on issues in the Fordwah Branch Irrigation System, along with Patrice Garin, researcher from CEMAGREF. First, an introduction of every body present was done by the field assistant to the farmer (a maximum of four people, including the field assistant, were admitted for a maximum time of 1.5 hours). The purpose of the discussion as well as the tools (cards) and procedures were reviewed with the farmer.

The meeting started with the presentation of the average sequence of the farmer, based on the harvested wheat samples. The farmer's opinion was asked after each practice was put down on the board and some had to be modified according to him. On the same board, wheat cycle was represented and plant critical stages were compared to the practices. From that basis, a discussion started concerning unusual practices, for example the reasons determining a late second irrigation for all the plots harvested.

The next step involved asking the farmer if that sequence was representative of all his plots, or if he used different sequences in different combinations of constraints. Discussion was continued on different scenarios of water deliveries. At that point in the discussion, the farmer was the main actor and used extra cards to represent ways he acted in different situations. Finally, we discussed the adequacy of proposed changes in farming practices.

III.5. Quality and precision of the results

III.5.1. Degree of precision required

Because of the high number of parameters, because the wheat cycle had not been followed from the very beginning, and because data had been collected in the fields instead of in experimental stations, it had been agreed at the beginning of this study that results would be rough.

For this reason, soil parameters like fertility, structure, etc. have been estimated rather than physically determined (see card user's guide in annex 5). Indeed, these parameters were used as surrounding indicators but were not detailed. When needed, available analysis were used (soil analysis, water analysis, tensiometer profiles).

For this reason also, parameters that were visually estimated were gathered in classes when they presented similar characteristics for further treatments. For instance, structure was expressed through a scale ranging from 0 to 2 (from very bad to good structure).

III.5.2. Measurement accuracy

Neither threshing machine nor grain automatic counter were available for the yield components analysis. This job was done by hand. Even with the most accurate supervision, some bags were mixed or lost, spikes and grains sometimes were lost during transport. Besides, out-of-command fields were left because canal water supply (or discharges at the head of the watercourses) were unknown. Fields that had different practices for each half of the field were also dropped (See the list of the samples dropped or that must be considered with care in annex 3).

For a few bags, losses approximated 10 spikes per bag. They are mentioned in the table A2 as unreliable, for them the error margin ranges from 13 kg to 100 kg per hectare, i.e 5.5 kg to 40 kg per acre. Moisture content of the samples can be approximated close to 13 percent because of the week the bags spent under the dry Pakistani sun.

III.5.3. Comparison with farmers' assessments and representativeness of the harvest sub-samples

For the four independent fields, yields measured by the responsible field assistant were used. We decided though that 4 m^2 would be harvested on one of these four sample plots so we could compare the results and see the variation proportions. We found a difference of 120 kg per acre, whereas a difference of 60 kg to 110 kg per acre was found with two farmers' declarations.

This needed to be done for all the plots in order to validate the results we use for yields and practices interpretations. Unfortunately data collection was delayed and no comparison could be undertaken.

IV. RESULTS AND DATA INTERPRETATION

IV.1. Wheat practices

For this report, practices are the overall of operations required to grow wheat correctly. These operations start before wheat is planted and finish with its harvest. They are connected to each other in a "technical sequence". They consist of soil preparation, sowing, watering, input use, treatment against weeds and eventually against salinity and mineral deficiency.

Based on the study of the 14 farmers, the first paragraphs present in a very qualitative way the general sequence used in Hasilpur area[1]. The next paragraphs focus in a more quantitative way on the variability of the practices and on the constraints that determine these variations. In order to clarify the text and ease its reading, a selection of the most significant actions was done. In particular, soil preparation varies widely but since it is not used much in the next steps, its variability was not developed.

IV.1.1. General description

Wheat is grown during Rabi season and can be sown from the end of October until the middle of January, after what potential yield is too weak to sow wheat. Nevertheless, sowing before November is very improbable, because of the cropping pattern and the land intensification. All farmers use pre-irrigation, also called rauni irrigation, approximately three weeks before sowing, because it puts soil in "wattar conditions" (i.e. best soil moisture conditions) for seed germination.

Soil was prepared by two to three ploughings just before sowing and one to two afterward (one or two days later). The two last ones are actually "ploughing renewal" and went less deep. Planking was also used once or twice after sowing in order to crumble the soil and prepare a better seed bed. While oxen were used for most of these operations, tractors (owned or rented) were used by the more wealthy farmers. Seeds, either for the market or mostly from the previous harvest, were broadcasted or scarcely sown in line with drill, and DAP was used simultaneously in dry soil.
Urea was applied three weeks after sowing, with the first irrigation, bringing more than 80 mm, because it improves its effects. Five irrigations were given, in total, approximately every three weeks, with an average amount of 80 mm. Urea was also applied with the second and third irrigations.

In saline and sodic areas, specific inputs like Gypsum and SSP had to be added and a special water management was required.

Harvest time starts the last two weeks of April, and continue until the end of May. In that case, risks of harvest losses due to rain and wind grow bigger. Thus, practices in this area of the Punjab show indices of intensification and a certain homogeneity in their practices which prove that the farmers are quite well informed about wheat requirements (Cf. recommendations of national agencies in annex 8). Still, major constraints remain which explain the established diversity both between and within farms.

[1] A. Bhatti and J.M. Wolf (1989) undertook a similar study in the Central Punjab that could be compared to the results described in the present paper.

IV.1.2. Variability of the practices

a/ Sowing

Sowing dose:

Depending on the variety, the type of soil and the date of sowing, the sowing dose ranges from 38 kg to 75 kg per acre, but majority use 50 kg per acre, as recommended by the local institutes. Experience on the eight watercourses confirms that Inqlab variety, hard sodic soils and late sowing doses are much higher than average seed rate : they reach 74 kg/acre for Inqlab variety sown on December 19th in wet clay soil (M. Nawaz) and 60 kg/acre for Pak 81 sown on January 20th (Qazi Ali). From December 15th on, doses increased.

Sowing time:

According to local institutes, the best time for sowing is November, but due to their cropping patterns, especially cotton, farmers are always late. Indeed, only 8 percent of the fields were sown before November 30th (earliest sowing starts on November 20th) after rice, sugarcane or fodder, 34 percent from November 30th to December 15th, 49 percent from December 15th to 31st. Eight percent were sown after January 1st, all after cotton.

Although farmers know yields will decrease with each day of belated sowing, some of them believe they might sow until the end of December, which is wrong. Some blame cash shortages as inhibitions to renting tractors or using fertilizers (M. Irschad).

This year because of rain farmers could hardly complete the sowing. In this case especially, practices differ among farmers which result in physically inhomogeneous looking fields. For example, M. Irshad sowed first half of the field on December 20th and the second half 11 days after. The second half looked 10 cm lower, with low density, irregular size and with smaller spikes. And Qazi Ali was almost one month late because of rain.

Variety:

Pak 81 and Inqlab are the most represented varieties. Varieties include Punjab and Biliou Star mixed with Pak 81. Inqlab is considered the best variety, better than Pak 81. Probably because of the scattering of seed availability, only a few farmers use it, which also explains why farmers mix Pak 81 with other varieties.

A high majority of the fields (85 percent) receive seeds from the previous harvest, though farmers know it is better to change them every two years in order to prevent yields from decreasing and to avoid diseases (Mehmood, 1995). Cash availability is certainly not a reason since neither farmers from Group 9 nor from Group 11, which both have the highest levels of investment, use seeds from market. The majority of farmers using market seeds belongs to Group 10 and Groups 1 and 4 to a less extent. Only the three best varieties are bought: Pak 81, Inqlab and Pasban.

Sowing depth:

Depth of sowing ranges from 1.5 inches to 6 inches, but most sow at 3 inches or 4 inches, a bit deeper than recommended. Results do not show up any general relationship between it and soil texture and structure, though farmers (M. Irshad and M. Nawaz) declared reaching 4 to 6 inches in dry hard soils, which cannot go without consequences for the germination rate.

b/ Crop rotations

Every year, the main rotation is wheat/cotton. It represented 56 percent of the patterns in 1994/1995. Cotton accounted for 67 percent of the rotations and wheat for 69 percent. Other crops are sugarcane, rice, fodder, vegetables (mostly melon), oil seeds, and fallow.

Table 7. Main four last years crop rotations.

Season	Wheat Cotton	Rotation including cotton	Rotation including wheat
1994/1995	56%	67%	69%
1993/1994	53%	60%	80%
1992/1993	51%	61%	79%
1991/1992	55%	31%	63%

The two last seasons show lower percentage, but data were not complete.

Nowadays, fallow is quite scarce: farmers used to use it with crop intensification. They tend to increase the quantity of inputs, when they can afford it. One of the sample farmers, Ghulam Hussain, asserted that because tubewells make soil preparation and crop management easier, fallow is no longer needed. For the past four years, 41 percent of the fields had no fallow and only five farmers used it from one to four months between Rabi and Kharif seasons. 31 percent of the plots had fallow for 6 months, whereas some have not for more than ten years.

c/ Land preparation

Ploughing:

Sometimes a few days after sowing, it rains which breaks the surface crust formed prevents young tillers from growing out of the soil and reduces the germination rate.
Plowing after sowing is supposed to be a way of saving time also, when Kharif crop's harvest is very late.

In sandy soils, total numbers are close to the average number, but when soils are too compact or tough, whatever their texture, the number of ploughings increases. In clay soils, total ploughings number a bit higher and range from twice to eight times in bad conditions. Some farmers believe that the more you plough, the better for seed germination (Mehmood, 1995). Farmers' behavior regarding that practice is very diverse, as follows:

> Whereas M. Yaqoob, who has good wheat yields, tends to prefer ploughing with a tractor after sowing rather than before, M. Irshad ploughed eight times with oxen and planked some of his fields three times before sowing.

Ploughing equipment:

Tractor ploughings increased with late sowing, while oxen ploughings decreased, because farmers were constrained by the date of sowing. Ploughing depth was significantly higher for M. Irschad, Elahi Bakhsh, Abdul Sattar and Siddique Haleem and in general for those who used higher tubewell water quantities. The harder the soil, the more farmers ploughed. But this was totally independent from the texture since contrarily to Siddique Haleem and M. Irshad, Elahi Bakhsh and Barkat Ali ploughed deeper in loamy/clay soils. According to Barkat Ali, tractors slide in sandy soils, keeping it from going so deep. In loamy soil though, depth is always more than 6 inches and seems to be a bit higher than in sandy soils.

Eventually, rotavator is used in order to squish crops remains, especially after cotton and sugarcane. The depth is 3 inches to 4 inches on average.

Levelling was used for three plots before sowing, given the fact that it removes big quantities of soil. No particular explanation was given for this.

d/ Fertilizers

Number of applications:

During the first month after sowing, many farmers apply fertilizer only once or not at all. The first month is the most efficient period for fertilizer application. Moreover, we noticed that the second application is often eluded because farmers wait for the wheat to boot to be sure it is worth applying fertilizer on a well-developed plant.

Quantities:

- Urea : principal doses for Urea are 50 kg, 75kg, and 100 kg per acre. But quantities range from 10 kg to 150 kg per acre. It seems that farmers either try to adjust fertilizers quantity as much as possible or reduce it too much because of financial constraints (Barkat Ali). On the other hand, some believe that the more fertilizer add ed, the better the yield, especially when sowing was late (Qazi Ali). It seems that doses were increased also when soil was hard, but no significant relationship could be found as farmers use relative comparisons within their plots. They used higher doses in the hardest of their fields soils, which was not necessarily the hardest of another farmer's field. To save money, urea instead of DAP was applied during sowing. The usefulness of the last application can be discussed because

fertilizers, especially Nitrogen, are not efficient when applied after booting (Sebillotte et al., 1978). Few farmers apply fertilizers in the second half of the crop cycle.

- DAP: 50 kg per acre was used mostly but the poorer farmers do not apply it at all. Very few farmers used interim quantities: 25 kg, 35 kg, 45 kg per acre. More expensive than urea, this fertilizer depends on farmers' cash availability, as Barkat Ali says. Beyond January 10th, DAP was not used anymore, though it was always applied once, during sowing (one day before or after). Because they did not have enough fertilizer, some farmers did not apply it to all their fields.

- SSP: It was used only in saline/sodic conditions to soften the soil as M Nawaz declared. Doses are either 50 kg, 100 kg or 150 kg per acre, depending on farmers, and mostly mixed with potash (M. Yussaf).

- Potash: This factor was not developed because only two farmers use it. It seems to be related to bad soil structure.

- Ammonium Nitrate, Nitro-phosphate: Same for SSP. First was used to replace urea or DAP shortage.

Table 8. Chemical composition of main fertilizers.

	Active components			
Fertilizer name in total percentage	Nitrogen content (N)	Phosphorus content (P)	Potash content (K)	Other
Urea	46	0	0	0
Calcium-Ammonio-Nitrate	26	0	2	Calcium : 8% Magnesium : 0.05% Zinc : 0.7%
Nitro-phosphate	23	23	0	Ca : 9% Mg : 0.1% Zn : 2%
SSP (Single Super Phosphate)	0	20	0.2	Ca : 20% Mg : 0.2% Zn : 12%
Potash (Potassium Sulfate)	0	0	50	Ca : 0.7% Mg : 1.2%
DAP	18	46	0	0

e/ Organic matter

Farm Yard Manure (FYM) was mainly used by farmers possessing livestock, because it is a precious element for combustion and it is hardly available on the market. Application consists in 4 trollees per acre (240 maunds) once every two, three or four years. Proportionately, Group 9 usee the most FYM, as it has one of the highest number of oxen per family, and cultivates in a very intensive way. Then come Group 3, with a high number of oxen and a low level of inputs, and Group 6, with a low number of oxen.

f/ Weeding

Decoran, Arilan and Bactril are chemicals used against weeds, that are still scarcely used. Doses range from 0.25 l to 1.2 l per acre, mostly 0.5 l per acre. More than all the other inputs, this one was determined by the farmer investment capacity - farmers from Groups 4, 9, 10 and 11 used it. But it was also related to previous crop cotton, because after this crop a lot of weeds remain and must be burned off occasionally. Indeed, 88 percent of concerned fields had cotton before. Harrow for weeding was scarce and though farmers preferred to hire manual labour to weed, most fields were not weeded at all.

g/ Irrigation practices

Number of applications:

Most plots received 5 to 6 irrigations including pre-irrigation (rauni irrigation), but the range was from 3 to 9 applications. Sandy soils received 8 or 9 applications; this was at the farmers discretion. In saline fields, the average number remains slightly the same with five applications, but standard deviation is quite smaller. Water supply and warabandi constraints explain why the number of irrigations is not actually related to the soil texture: farmers do not use water when and how they need it.

Table 9. Percentage of tubewell water for each irrigation event.

Number of applications after sowing	Tubewell water percentage in non saline fields	Tubewell percentage in saline fields	Population
2	31	100	2
3	48	88	6
4	63	67	15
5	72	93	23
6	73	0	8
7	95	0	1
8	95	0	1

Dates of applications:

It was found that even for farmers using mostly tubewell, no rule existed concerning the irrigations frequency. It looked as if each farmer had his own way: some farmers applied water depending on the plant's appearance (Mehmood, 1995) but some applied water exactly every 30 days regardless of plant needs. Another using only tubewell gave a maximum of applications and biggest volumes but had no salinity. Farmers strategies definitely need to be studied to understand water allocation.

Only the first irrigation seemed to occur one week later in saline fields, probably due to the higher amount of water given for the pre-irrigation. First application delay is mostly respected, but following irrigations tend to be belated.

Table 10. Irrigation dates for the 56 sample plots.

Date of application	Earliest (in days after sowing)	Latest (in days after sowing)
First irrigation	1	60
Second irrigation	20	102
Third irrigation	37	118
Fourth irrigation	61	124
Fifth irrigation	71	126
Sixth irrigation	93	123

Water quantities:

Average global quantity including pre-irrigation is 1821 m^3/acre (455 mm), with extremes ranging from 794 ^{3}/acre (200) to 3608 ^{3}/acre (900 mm), which is enormous. Considering the rainfalls (which are much higher this year), total water given for the Rabi season can go up to 3916 ^{3}/acre (980), which is 80 percent to 140 percent more than recommended in this area. In saline fields the total volume is smaller with 1358 ^{3} per acre in average and a standard deviation half smaller too. No saline field receives more than 2000 ^{3}/acre, the maximum recommended, even though these farmers use the highest tubewell water percentage.

Besides, global quantity increases with the percentage of tubewell and inversely decreases with canal percentage.

Average quantities applied before sowing and ploughing are slightly smaller in saline fields because of sodicity effects. Indeed, soil structure is destroyed and water infiltration is much less. Rauni irrigation represents a higher percentage (24 percent against 16 percent), probably in order to leach salts before sowing.

The first irrigation after sowing brings a higher amount of water whatever the number of applications. But the difference tends to disappear when the total number of irrigations increases, and before last irrigation gives a second main contribution. Volume are always a bit lower in saline fields. For that we assume strongly that salinity does not go without sodicity, which reduces considerably the water infiltration. Therefore applications have to be smaller.

Even if the total amount of water has no link with the date of sowing, it appears clearly that the later the wheat has been sown, the more water the field received. This is probably a way to save time as well.

Water quality:

Canal water quality is considered much better because it contains silt which increase soil fertility (Mehmood, 1995). Among the sample fields none receives poor quality tubewell water. Seventy four percent of the total irrigation water is supplied by tubewell, 69 percent in non-saline fields and 80 percent in saline fields.

Quality of water is especially important during the first period of wheat, but considering canal water availability, farmers do not have that much choice. It appears anyway that this parameter does not have an impact on farmers' decision, probably, as mentioned previously, because of the relatively good quality of water in the sample area.

Tubewell water for rauni irrigation is used for 48 percent of the plots (where 4 percent mix it with canal water), but for the first crop irrigation, the figure becomes 86 percent (where 15 percent mix it). A lower percentage (74 percent) is used for the second and third irrigations, as canal water becomes scarcer. This slight diminution is due to the fact that the first irrigation is usually bigger than the others. In saline fields, figures become 57 percent for rauni irrigation and 93 percent for the first irrigation.

It is interesting to note that only farmers from Fordwah 130-R mix canal and tubewell waters.

The data show that canal water is already missing at the end of Kharif season, and shortage occur more often. Shakar Ali, from Fordwah 14-R, declared that every year water stops running from February to March because of big farms upstream. Most farmers avoid tubewells for rauni irrigation, but for them quantity was more important than quality, even in saline fields. Farmers from Fordwah 130-R and Fordwah 62-R are less constrained by canal water. Those on Azim 111-L use tubewell water only as canal water is not available during the Rabi season. Farmers from Fordwah 130-R also use tubewells a lot; these are bigger farms, using a greater amount of tubewell water that cannot be completely supplied by canal that hardly reaches the end of the canal.

h/ Salinity

According to field observations and farmers assessment, 30 percent of the plots suffer from salinity and sodicity, with 24 percent of white salinity. But according to salinity records from January 1995, only 7 percent is reported as been affected.

Azim 111-L, Fordwah 14-R and Fordwah 130-R suffer from white salinity. Black salinity (toxicity) has only been identified on Azim 111-L.

Gypsum is only applied in fields with white saline. However, only 60 percent of the total white saline fields have received gypsum. Besides, 66 percent of the fields previously classified in non-saline areas received gypsum too. Groups 4 and 9 use it the most as they do not face any cash availability constraint.

Gypsum application consisted of 400 kg (10 bags) per acre applied once before sowing (Qazi Ali, M. Yussaf) or 50 kg per acre (1 bag) of "expensive gypsum", which is provided by the owner (Yussaf).

When the degree of salinity gets lower, SSP can be used instead of gypsum. We noticed that SSP was always used in sodic soils. Whereas M. Nawaz used it the same as M. Yussaf, to soften soils with potash, Qazi M. Ali uses it because of gypsum's price rise. It is also recommended by the Hasilpur Agricultural Department.

Among the other treatments, some farmer choose to dig the first 60 cm of soil surface and bring some new sandy soil, which seems to work better for Barkat Ali and Abdul Sattar A-111 than for Ghulam Hussain. Salinity grass and rice enter also into the crop rotations in saline area because they improve soil fertility and reduce salinity. Shakar Ali had salinity more than 40 years ago,and he eliminated it only by proper water management practices, thanks also to the apparition of tubewells in the area, which lowered the water table level.

i/ Discussion

Through these 56 plots and 14 farms, it seems relatively easy to determine the reasons for differences of sequences for all the parameters except for soil preparation and irrigation. Indeed, cash flow limits farmers greatly for all the inputs and machineries, causing serious consequences for the whole following season; crop rotations are determined by the seasons and farmers' objectives (often linked to cash availability) and by salinity in a less extend. Farm yard manure is related to livestock ownership ; sowing doses and dates are related to numerous identified factors. Salinity requires specific actions to manage it well, but soil seems so diverse that it was not possible to determine a rule. Most disturbing was that we only could use a relative scale.

For water, it is even more complicated. Quality and quantity could be related to salinity and tubewell water availability and farmers' location on the watercourses. The number of irrigations could be linked to soil texture and tubewells use. But no Explanation could be made as to why some farmers apply way too much water. It was particularly interesting to note that those farmers are not in saline conditions. To the opposite, lower volumes are applied on saline fields. Irrigation frequency could not be explained either. In fact, at this stage of the study, few was understood about the differences (sometimes huge) in water allocation within a farm.

In this section, practices variations were described factor by factor. However, some of these variations are correlated. Therefore, the main combinations are identified.

IV.1.3. A simplified typology of wheat practices

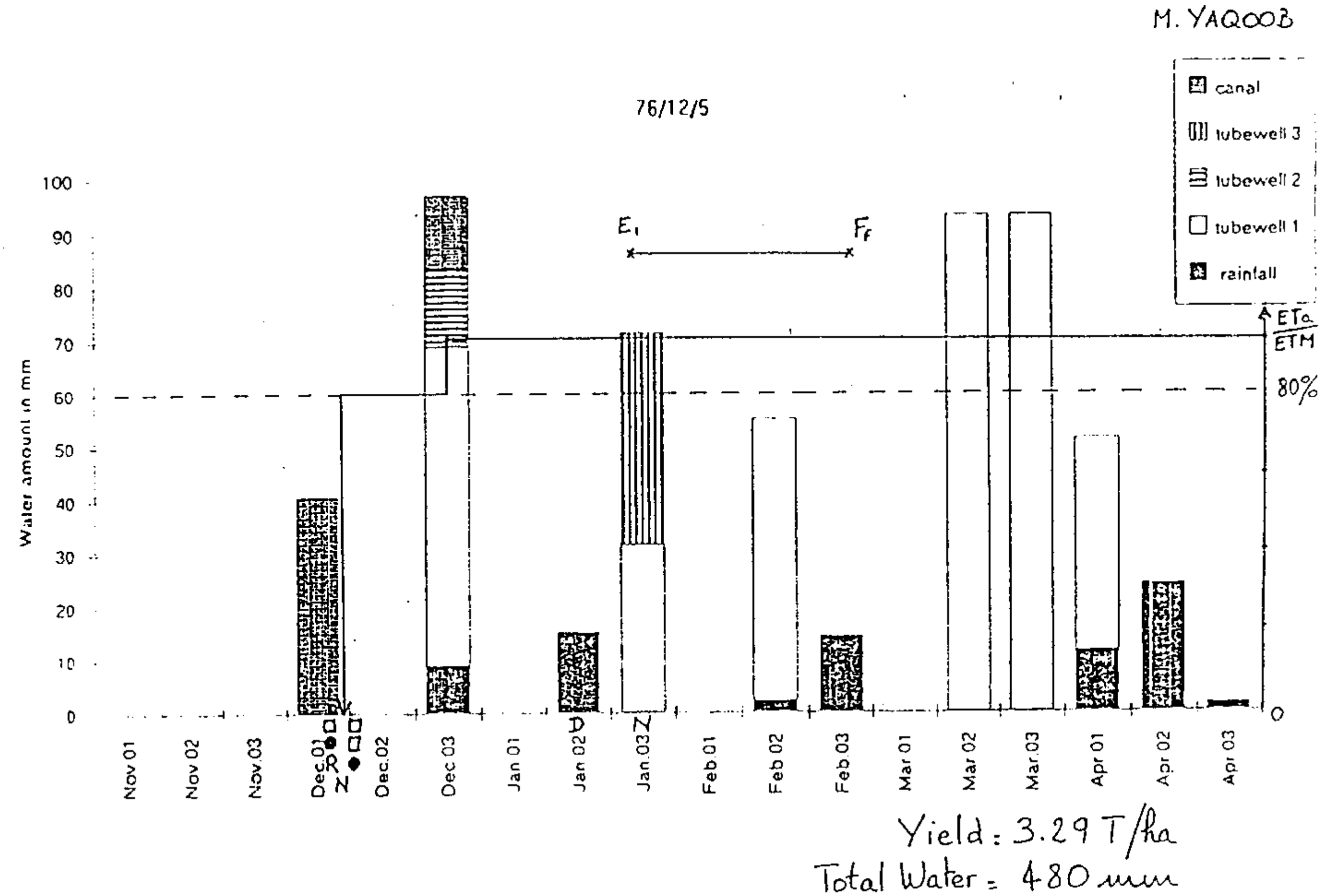
a/ Intensification via input consumption and tubewell water use (P1)

Wheat is sown relatively late (end of December). Since some of these farmers used a rotavator, cotton crop can be destroyed and land prepared for wheat in a very short time after the last cotton picking. However, the relatively wide range of sowing date observed for some farms (farm) can be explained by machinery constraint due to the large landholding size. Owner-operated tractors were used for land preparation, which gave some flexibility.

The average level of input consumption is rather high (fertilizers and chemicals)
The main characteristic of this practice lies in the good adequacy and timeliness of wheat irrigation

(see Graph 1). No moisture important stress is observed during the critical period (between booting and flowering stage). Farmers do not hesitate to operate their tubewells or to purchase water if their well was used to capacity. Tubewell water seems to be the major source of irrigation, and canal water, with an unpredictable supplies, was used as a complement when available. These practices are mainly carried out by farms 220. 277. 275.

Graph 1. Example of irrigation schedule diagram of farm 277.



b/ Intensification via input consumption and canal water use (P2)

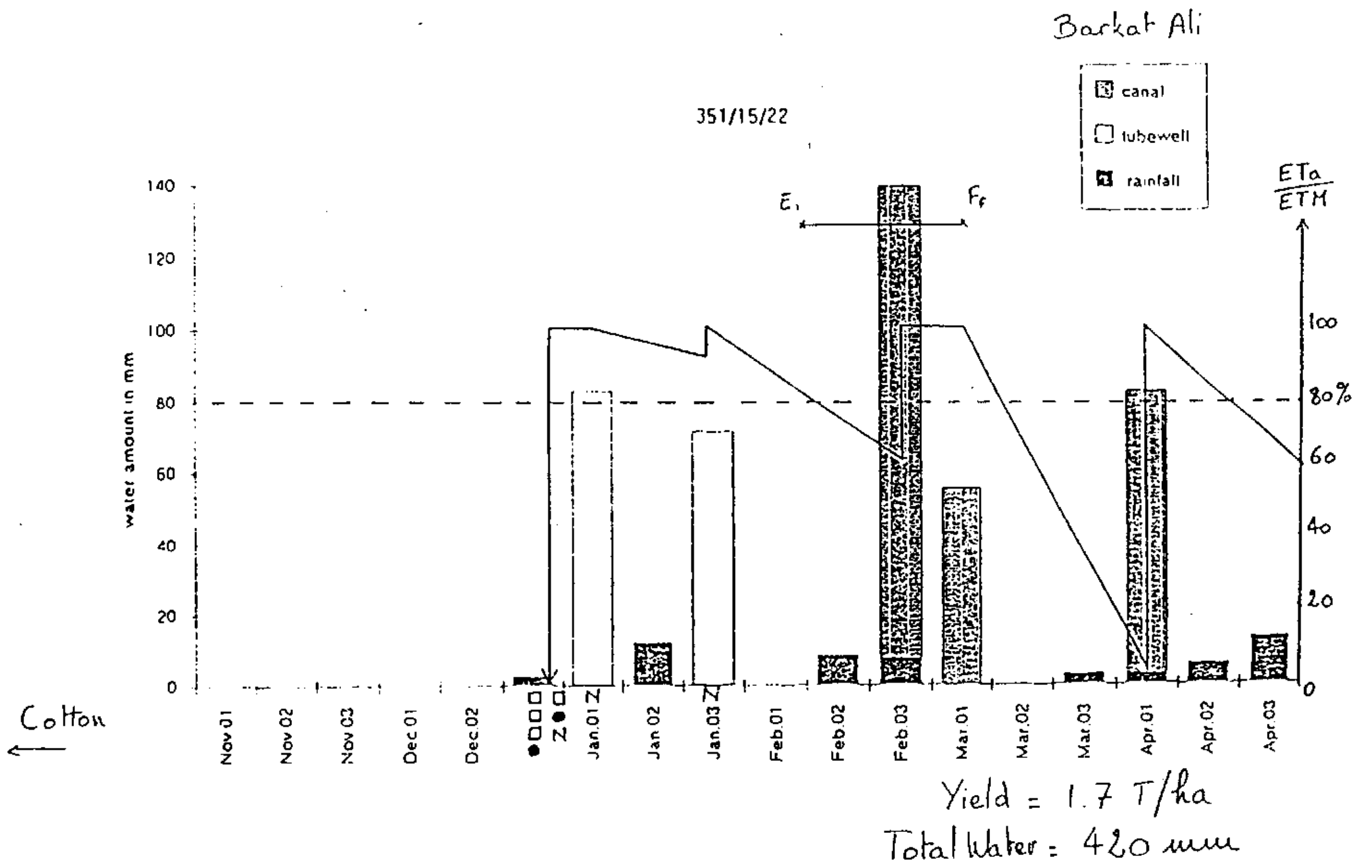
Pre-sowing irrigation is exclusively done with canal water. Farmers irrigate a few fields at each water turn, which explains why sowing dates are spread through a month.

Owner-operated tractor was used for land preparation (tractor availability was not a constraint) and input consumption was quite high (fertilizers).

The main difference with the practice (P1) is related to irrigation. Most of the irrigation was done with canal water with relatively adequate supply but uncertain delivery dates. Tubewell water is then used to complement canal water supply when it doesn't match the crop water requirements (mixed irrigations). Pure tubewell water irrigations remained rare, but was observed during the canal closing period in January. The timing of irrigation was more or less imposed by canal water deliveries, which led to moisture stress in some cases (farmer delay irrigation when canal water is not available even if the crop is stressed). Such a stress is obvious for farmer 136 (see Graph 2).

These practices were mainly carried out by farms 47 and 136 and, in a less intensive manner by farm 249.

Graph 2. Example of irrigation schedule diagram of farm 136.



c/ Intensification via labor (P3)

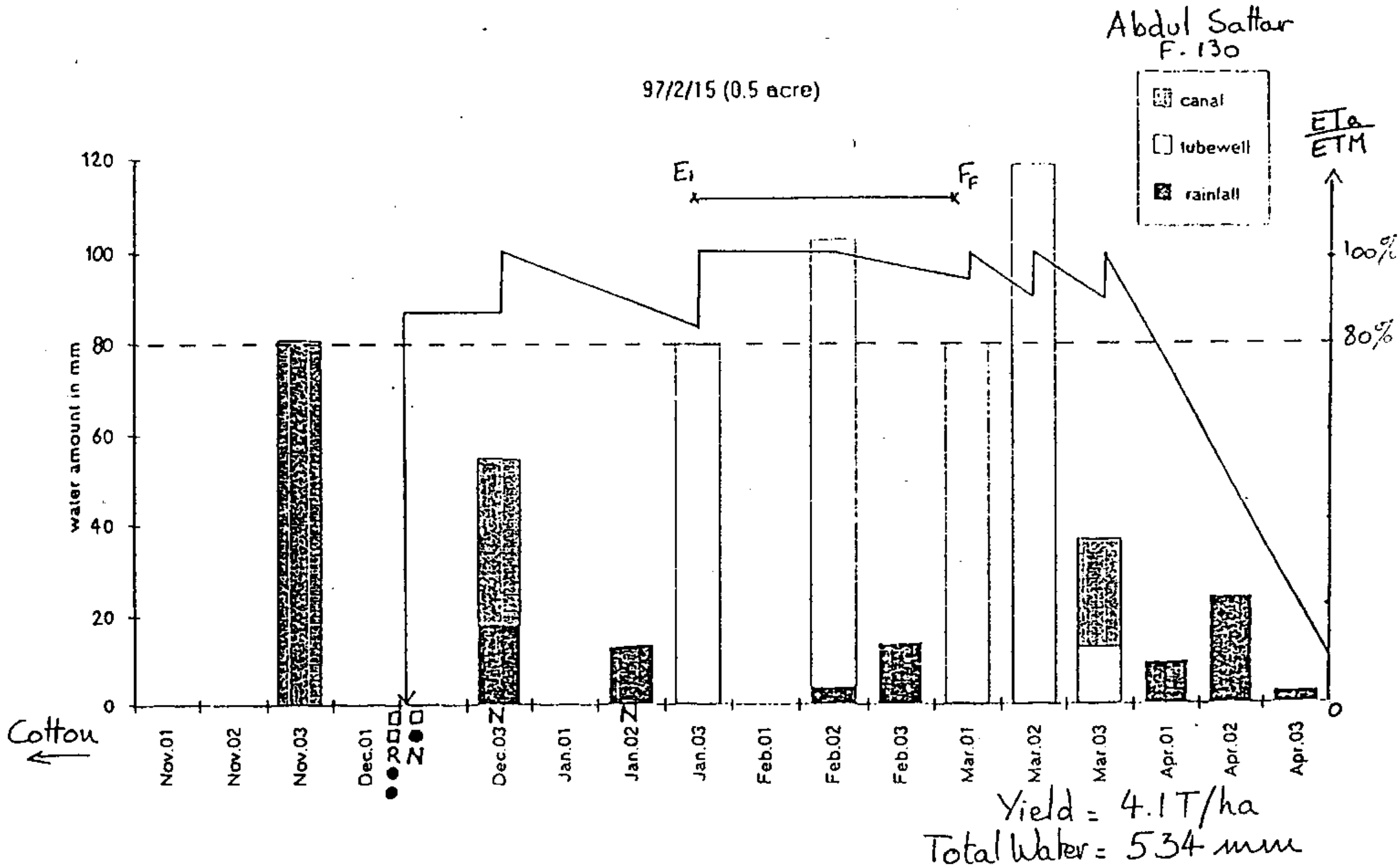
Wheat is not sown before the beginning of December, after a late last cotton picking.

Land preparation was done with oxen because hiring a tractor would further delay the sowing date. This activity requires a lot of labor.

The level of input consumption is relatively low but efficiently used (the total quantity is applied with pre-sowing, first and second irrigation in small quantities).

Tubewell water is purchased to compensate canal supply uncertainty, and to avoid moisture stress. Graph 3 shows that the ratio ETA over ETM is always above 80 percent for farm 267.
The yields obtained are among the highest recorded (2.73 Ton per ha on average for the group, and above 3.5 T/ha for the farm 267). These practices are observed for farms 267 and 208.

Graph 3. Example of irrigation schedule diagram of farm 267.



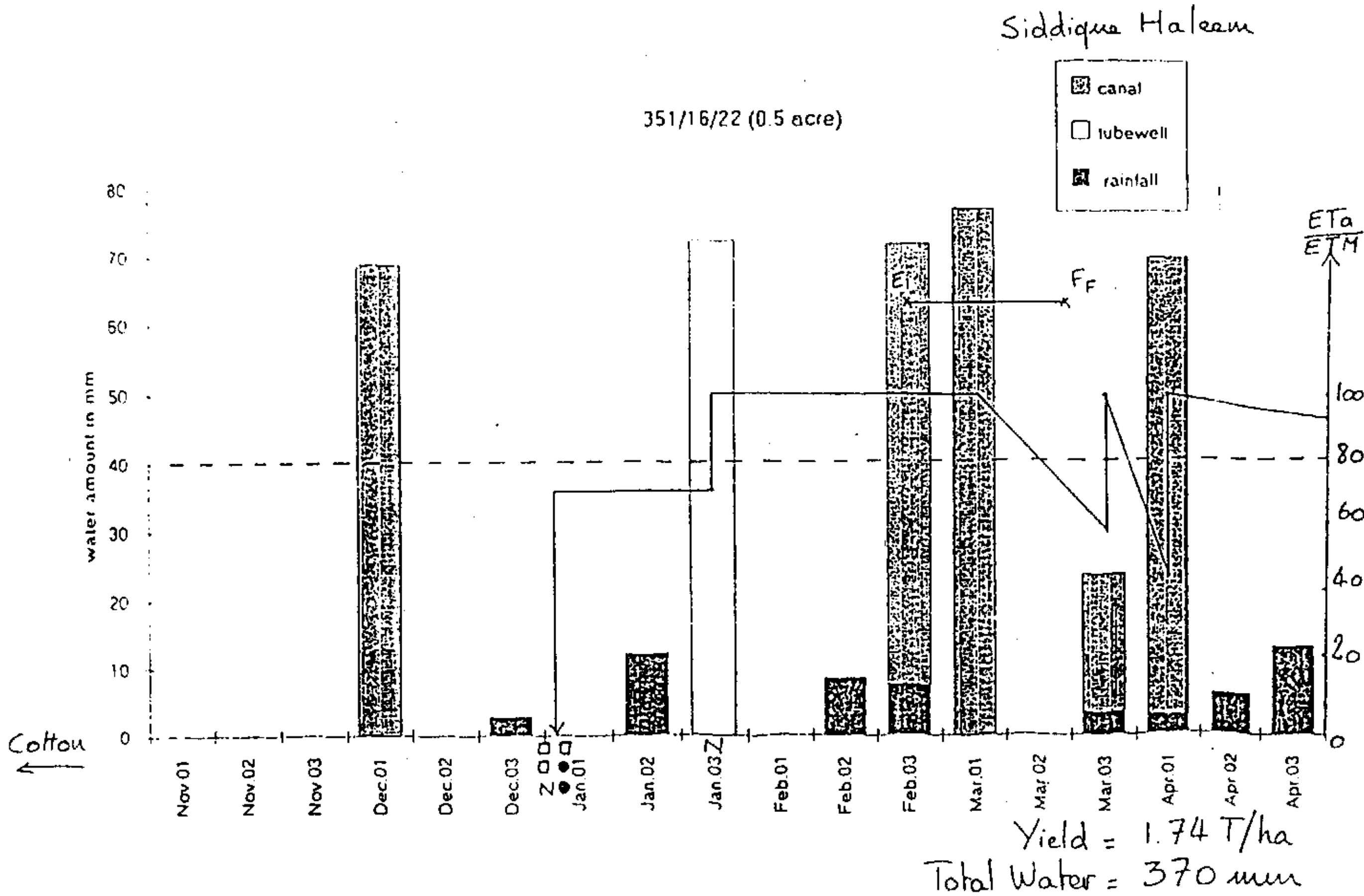
d/ Extensification (P4)

Sowing is done relatively late, since farmers prefer to make an additional cotton picking (cash crop). The late sowing date is also because the tractor, which has be hired for land preparation was not available. The delay of wheat sowing has a strong impact on the yields obtained.

The use of purchased inputs was limited; only domestic seeds were used, the quantity of fertilizer did not exceed 50 kg of DAP and 75 kg of Urea and their use was sometimes not optimal (Urea was applied at flowering stage by farmer 191).
Canal water supply uncertainty was not compensated with tubewell water purchase which sometimes led to important moisture stress. Tubewell water was supplied to the crop to save it, not to secure a yield. The importance of stress affecting the crop at different stages is shown in Graph 4 for farm 140.

These practices were observed on farms 133, 140, 191 and 66.

Graph 4. Example of irrigation schedule diagram of farm 133.



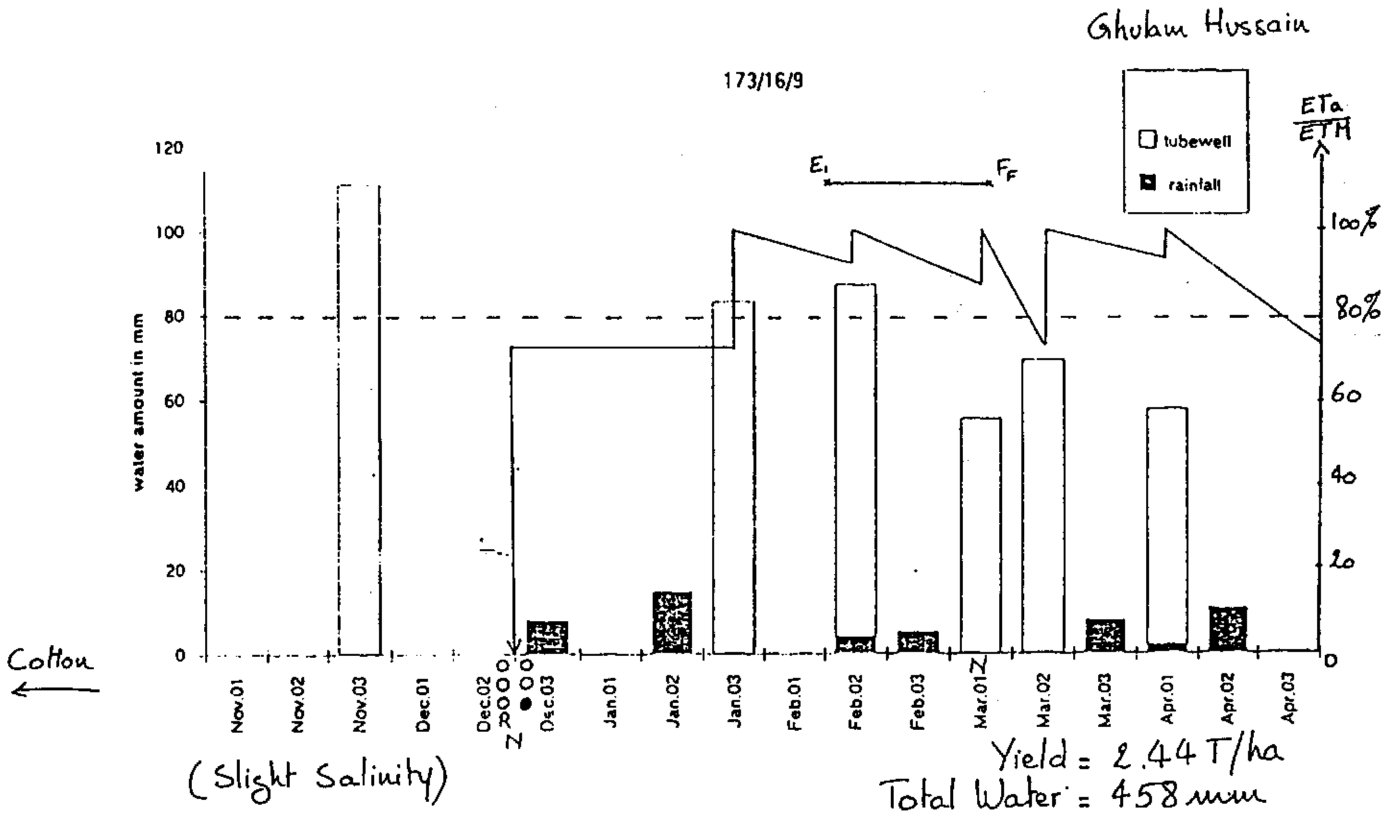
e/ Wheat practices related to salinity (P5)

Sodicity and salinity affect the structure of the soil and may affect wheat development in its early stage (low germination rate). In such fields, farmers minimized the use of inputs such as fertilizers when they were not sure the yield would cover the input expenses. In some cases, fertilizers were applied after the flowering stage (when farmers have an idea of the yield size), at a time the plant can't absorb the nitrogen any more. Farmer also assume that the marginal productivity of inputs such as fertilizers is much less in saline and sodic fields as in good fields which justify relatively extensive practices.

In fields affected by sodicity, water infiltration is quite slow, which explains that the quantities of water supplied by farmers were very small (from 40 mm to 80 mm).(see graph 5).

Another characteristic of these practices lies in the rotation wheat-rice -wheat-salinity grass

Graph 5. Example of irrigation schedule diagram of farm 210.



IV.2. Practices, strategies and production objectives

Wheat practices are determined by a rules that a farmer adopts to allocate among crops a limited amount of resources (strategy) under certain constraints (water supply, salinity) to achieve a more global objective. This section aims at highlighting the relationship between production objectives, strategies and wheat practices. For more details about objectives, strategies and practices farm by farm, see annex 9.

IV.2.1. A few definitions

By set of production rules or *strategy*, we mean the principles that farmer follows when allocating resources to the different activities, crops or fields (for instance, one rule or strategy gives priority to wheat over fodder in water allocation). The resource can be a physical resource (land, water) as well as an economic resource (input purchase, labour or machinery availability). These rules determine the way the resources are allocated in space and time (for instance, the allocation over time of canal water for pre-sowing irrigation determines the sowing date and has a strong impact on the final yield)

The term *objectives* will be understood in a more socio-economical way as the global objectives of production activities. The objectives of a farmer can be, for instance, profit maximization, saline land reclamation, subsistence, etc.

The *importance of wheat* in these objectives refers to wheat contribution in the achievement of the global objectives.

IV.2.2. What determines wheat practices?

The two main production objectives that were identified through the farming system analysis are (i) production for own farm consumption versus (ii) market oriented production. However, the typology also stressed that groups having the same objective often face a different set of constraints which explains why they sometimes adopt opposite strategies.

a/ Profit maximizing objective

Profit maximizing is the objective of Groups 2, 3, 4, 5, 6, 9, 10 and 11. Farming activities represent the main source of household cash income for these farms. When the water supply is adequate, diversification of the cropping pattern and cultivation of profitable crops such as sugarcane is one of the possible strategies (Groups 2 and 3). Wheat is then mainly grown for autoconsumption. If water supply is a limiting factor, specialization in less water-demanding crops (cotton, wheat) and intensification of the production can provide a marketable surplus and cash income (Groups 4, 5, 6). A secondary objective of wheat cultivation remains autoconsumption. Diversification of the cropping patterns and intensification of cotton and wheat (high level of input consumption, tubewell water use and purchase) is a third strategy chosen by farmers of Groups 9, 11 and, to a smaller extent (lower level of cotton-wheat intensification), of Group 10.

These strategies and specific constraints (salinity) or resources (credit) determine the wheat practices. For farms in Groups 2 and 3, priority was given to diversification crops in production factors allocation. As the resources of the farm are rather limited (credit constraint, no tubewell) the wheat practices were relatively extensive (practice P4).

Although the objective of farms from Groups 9 and 11 (large landholding and mechanized farms) is also profit maximizing, the strategy they developed is radically different from Groups 2 and 3. The absence of credit constraint enables them to intensify production (inputs purchase, tubewell investment and tubewell water purchase). The wheat practices can be characterized as intensive (practices P1 and P2). Practices of Group 10, although they show some similarities with those of Groups 9 and 11 (P1), are adapted to the high level of salinity and sodicity of the land (practice P5).
Market-oriented Groups 4, 5 and 6 try to maximize the household cash income by specializing in cotton and wheat. Water supply (canal water supply is not complemented by tubewell investment) and short-term credit (input purchase) are the two main constraints preventing them from reaching the same level of intensification as Groups 9 and 11 (practices P1-P2). The wheat practices correspond to a less intensive version of P2 (a tractor is hired, the level of input is lower and timeliness of irrigation can be improved).

The links between global strategies, wheat strategies and wheat practices are summarized in table 11.

Table 11. From strategies to wheat practices for profit maximizing groups.

Global strategy	Wheat-cotton specialization			Diversified cropping pattern				
	-less intensive	-intensive (inputs, TW water purchase)		-priority to diversification crops		-tubewell investment -priority to cotton wheat		
Wheat strategy	autoconsumption surplus sold			-extensive cultivation (few , inputs) -auto consumption		-intensive cultivation (inputs, TW water) -cash crop and autoconsumption		
Group	4	5	6	2	3	9	11	10
Sample farms	**249**	-	**208**	**66**	**191**	**47 277 136**	**275 220**	**210 213**
Practices	**P2 (less intensive)**			**P4**		**P1-P2**		**P5**

b/ Subsistence objective

For Groups 1, 7 and 8, the objective of farming activities is to provide enough staple food to match family requirements (autoconsumption or subsistence objective). However, different strategies are adopted to achieve this objective. Farmers from Groups 1 and 8 produce wheat extensively (low variable cost per hectare) while farmers from Group 7, cultivating a very small area (1.45 hectare on average for the group) have a very intensive production, characterized by a high level of input consumption and tubewell water purchases to compensate the poor canal water supply. Wheat practices of Group 1 are extensive with a limited input use and rare tubewell water purchase (practice P4). Practices of Group 8 are also extensive, but also adapted to the high level of salinity and sodicity that affect the fields (practice P4-P5). Group 7 practices are characterized by a high labour intensity (no tractor use) but intensification is constrained by credit shortage (practices P3). The links between global strategies, wheat strategies and wheat practices are summarized in table 12.

Table 12. From strategies to wheat practices for autoconsumption-oriented groups.

Global strategy	no diversification cotton wheat specialization		
	-rare TW water purchase -low CI	-rare TW water purchase -low C	- TW investment or TW water purchase -high CI -high productivity of the land : labour and inputs intensification rare TW water purchase
Wheat strategy	-extensive	-extensive -high total family requirements for auto consumption	-intensive -high family requirements per acre for autoconsumption
	-small marketable surplus	-small marketable surplus	-small marketable surplus
Group	1	8	7
Sample farm	133, 140	104 (not analyzed)	267
Practices	P4	(P4-P5)	P3

This type of analysis underlines that wheat practices are determined by specific farm constraints, global farm objectives and strategies.

The practices partly explain the levels of yield obtained by the sample farmers. An in-depth analysis of the relationship between yield and practices is required to stress the determinant factors of the final yields.

IV.3. Wheat final yield

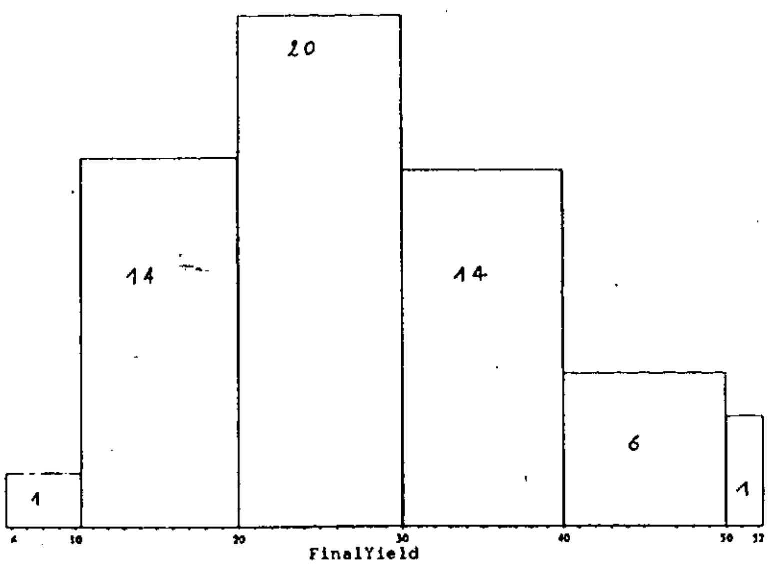
IV.3.1. Presentation of the results

a/ Wheat yields obtained in Rabi 1994/1995 in Hasilpur area

In this chapter, the term wheat yield is used for grain yield, given that the straw yield is less importance for this study's objective.

The average wheat yield obtained through 56 plots was 26,87 maunds per acre, ranging from a maximum of 52,3 maunds per acre (5,23 T/ha) with excellent cultural practices (see recommendations in annex 8) to a minimum of 10,4 maunds per acre (1 T/ha), which is more than five times inferior. Only one plot yield was less than 10 maunds per acre, with 5,67 maunds per acre (0.5 T/ha), but this result is considered exceptional and not representative of the samples.

Graph 6. Wheat yield distribution for Rabi 1994/1995 in maunds/acre for 56 plots.



Harvest samples are expected to overestimate field yields because they do not take in account the borders effects (less fertilizers, irregular soil preparation, etc.). Transports losses, labor salaries and miscellaneous losses are not accounted for in the harvest samples. For these reasons, it is necessary to compare the samples yields to the field yields stated by the farmers to determine the representativeness of the sample in the plot. Only two results were compared to farmers' yields, which did not allow for any conclusions concerning this representativeness. In these cases, an overestimation of 61 kg to 115 kg per acre was found, which is still acceptable. Table 13 gives an idea of yields distribution and representativeness among the farmers and the watercourses.

Table 13. Five best and worst yields results.

Best yields (maunds/acre or Qx/ha)	Plot number	Farmer's name	Watercourse
52,34	173/11/15	Qazi Ali	A 111
48,93	77/13/3	M. Islam	F 130
45,70	76/16/16	M. Yaqoob	F 130
45,44	550/9/11	Shakar Ali	F 14
45,38	97/2/10	M. Yussaf	F 130
Worst yields (maunds/acre or Qx/ha)	**Plot number**	**Farmer's name**	**Watercourse**
5,67	97/2/3	M. Yussaf	F 130
10,47	ooc/18	Siddique Haleem	F 62
11,68	410/11/13	Elahi Bakhsh	F 46
12,78	506/15/13	M. Irshad	A 20
13,82	351/16/1	Barkat Ali	F 62

b/ Wheat components

The grain yield is a function of its components which are, according to Meynard et al. (1988), :

- the number of plants/m²,
- the number of spikes/m²,
- the number of grains/m²,
- the weight of 1 grain.

If the number of spikes/m² was very low, compared to the average value, there must have been a problem during the germination until the end of the booting stage. At that time, the combination of fertilizer and water is most important. If the number of grain per spike is low, an accident must have occurred during the flowering stage, making the flowers abort. But an accident before that period may already have reduced the potential number of spikes per m². A low weight of grains is the result of an accident after the anthesis. (It may be the high temperature effect (casual when the wheat is sowed late).

From the data collected in the fields, yield has been decomposed according to:

grain yield = number of spikes/m² * number of grain per spike * weight of one grain

The final number of spike was manually counted. The percentage of empty ones (no spring apparition) could not be measured. The number of grains per spike (NGS) was calculated from the weight of thousand grains (WTG), the total sample grain weight (TW) and the total number of sample spikes (NS), as follows :

$$NGS = (NS / TW) * WTG$$

Graph 7. Yield components distribution in kg/acre for 56 plots.

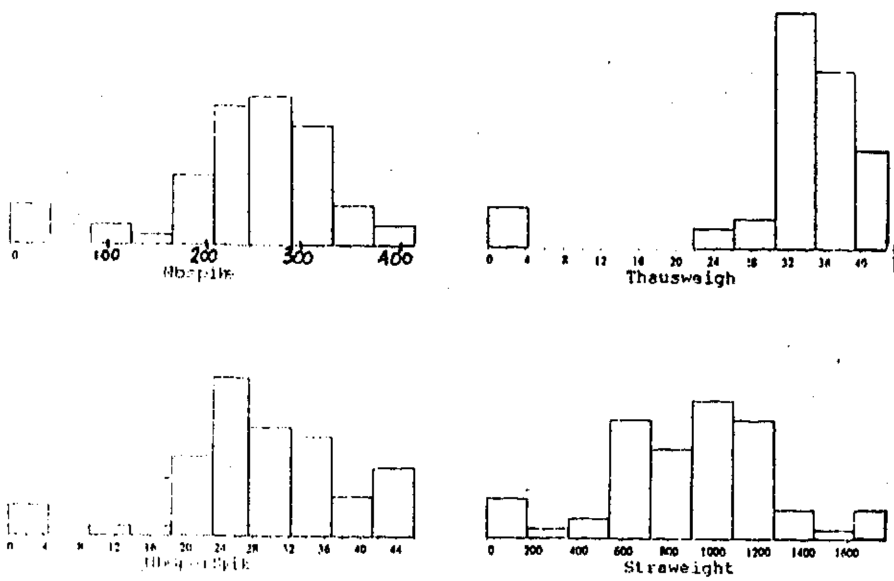


Table 14. Wheat components distribution.

Wheat components	Maximum	Minimum
Wheat density	416 spikes per m2	95 spikes per m2
Number of grains per spike	46	12
Weight of thousand grains	43.7 grammes	23.2 grammes
Dry matter weight	453 grammes per m2	56 grammes per m2

IV.3.2. First conclusions on these results

The results obtained on these 56 plots have a large range, but give a good representativeness of the local area production, since the average yield figure is only 2 maunds less than the average given by the agricultural department in Hasilpur for this season. Also, according to the farmers, results are a bit higher (between four and six maunds per acre) this year, due to climate and rain, which was confirmed by the agricultural department.

The maximum yield is 1 ton per acre less than the maximum potential yield in this area, which is 6.42 T/ha (Hasilpur Agricultural Department, May 1995) obtained with early sowing and after six months fallow. The difference comes from the poor quality of the sodic soil, which has bad structure.

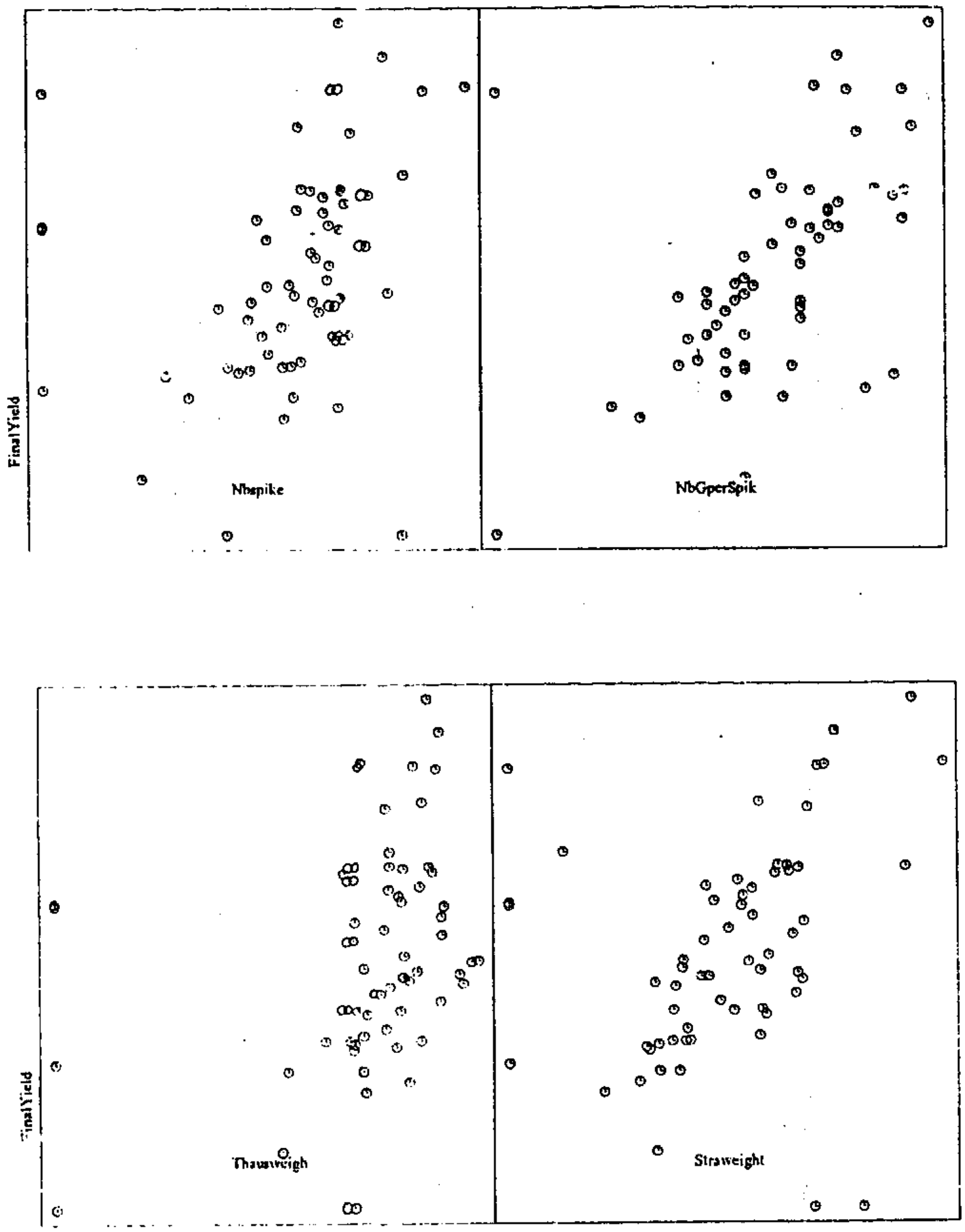
Bhatti et al. (1988) found similar figures for number of spikes per m^2 (from 99 to 440) but slightly higher yields (1.2 to 7.3 T/ha) in Punjab. Meynard & Sebillotte (1983) found an number of spikes per $m^2$2 ranging from 395 to 518 and an average number of grains per spike of 35 in France, whereas Sebillotte et al. (1977) found 25 grains per spike on average and 420 to 490 spikes per $m^2$2. Weight of thousand grains was 33 g.

Annex 7 presents details of the five best and worse component results and their representativeness among the farmers and the watercourses.

IV.3.3. Relationship between the final yield and its components

A significant relationship exists between the final yield and the number of grains per spike ($R=0.59$ and no percentage of error). Grain yield is also significantly related to the other components, but to a less extent : $R=0.31$ with 1 percent error for the straw weight, $R=0.3$ and 2 percent error for the weight of thousand grains and $R=0.28$ with 3 percent error for the number of spikes per m2.

Graph 8. Relationship between final wheat yield and its components.



This graph shows that wheat has been particularly sensitive to the period when the number of grains per spike have developed. This corresponds to the beginning of the booting to the end of the flowering stage (Cf. Fig. 1 in the Literature Review). As a consequence, the research of the main factors having an impact on final yields have focused on the events and practices occurring during this particular period.

Unfortunately, so many factors are interrelated and their effects are mostly not punctual, but last for days, that we had to restart from the whole cycle to find relationship between yield and external factors. In the next step, yield was expressed as a function of theses factors for the critical period in a production function.

IV.4. Impact of external factors on yields

Given the small sample and the numerous external factors influencing final wheat yield, the following results should be considered with care.

IV.4.1. Irrigation

The first observation is that wheat yield is slightly related to the total water quantity (R=0.29), and hardly to the number of irrigations. Also, final yield is greatly related to total tubewell water percentage (R=0.47) and inversely related to canal water percentage. Farmers can make use of tubewells whenever they need it, whereas they only can use canal water when warabandi affords it.

For equal total water amount, farmer using tubewell water will have better results than farmer using canal water, because of better irrigation flexibility and adequacy. The following graph shows that on average not even half of the theoretical maximum yield is obtained with total required amount of water. Though, yields keep on increasing after the threshold, this emphasizes the low efficiency of farmers' irrigation practices.

Moreover, opposite correlation coefficients were found between the final yield and the total amount of water in saline and non-saline fields; in the second situation, the more water given, the higher yield obtained (0.31); in the first case, better yields are obtained with less water (R=-0.21). Sodicity and water stagnation are the main reason for that.

Linked to the total water quantity, the percentage of tubewell has a positive impact on the number of spikes (R=0.33) more than on the number of grains per spike and on the weight of straws (R=0.21), but not at all on the weight of thousand grains. Referring to the wheat cycle, it seems to confirm the predominance of a good water supply before anthesis, because of higher plant sensitivity.

The date of the first irrigation after sowing has the most important impact on final yield (R=-0.35), on the number of spikes (R=-0.32), the weight of thousand grains (R=-0.28) and the weight of straws (R=-0.25). The later it occurs, the more the plant is damaged. Importance of irrigation during the crown root initiation appears here clearly and consequences on all the following steps also. To the opposite, last irrigations do not seem to have any impact on any component.

Observations on watering schedules led to understanding the impact of irrigation on yields.

IV.4.2. Soils and salinity

Despite farmers' assertions and impact evidence, no obvious relationship between yield and salinity could be shown through the 56 plot samples. First of all, salinity data were not accurate enough; secondly, farmers' practices are often sufficient to limit major effects of salinity; and, thirdly, salinity is related to too many factors, such as soil structure, water quality, quantity of water for each irrigation, to be able to isolate each factor from another in that type of study.

Nevertheless, the number of spikes per m^2 is significantly lower in saline fields. Thus impact of salinity on the first wheat stages appears.

a/ Effect of soil on wheat roots and plant development

Assertions made here have been deduced from the observation of only four soil profiles, details of which can be found in annex 6. Obviously, and despite farmers' declarations (three out of four said that wheat roots do not go deeper than one foot), it seemed that beyond 50 cm deep wheat roots keep on growing. Nevertheless, questions exist concerning the theoretical maximum depth, taken as 1.5 m. Indeed, general middle to bad soil, casual water shortage and poor plant aspects let us think that roots depth do not overpass 1 m. This assumption could not be verified.

Moreover, no particularly bad cultural consequence, such as a compact horizon, seemed to prevent roots from growing vertically and no parasite seemed to attack or disturb their development. Even so, a largely lower density than asserted by Klepper et al. (1985), quoted in Musick et Porter, 1990, was found. They reported that a root length density of 6 cm/cm^3 in surface soil are common while densities of 1 cm/cm^3 are found at the 0.5 to 1.0 m depth. A rough approximation for these six profiles gives:

- in the surface soil : 15 roots * 6 cm length * 6 = 540 cm/125 cm3 = 4.32 cm/cm^3

- in deep soil (around 50 cm) : 2 roots * 6 cm length * 6 = 72 cm/125 cm3 = 0.58 cm/cm^3

which is largely underestimated. But comparison should stay relative because no indication is given concerning the soil texture.

b/ Soil preparation

No correlation could be found between the number of ploughings or the depth of ploughings and any of the yield components. A weak tendency shows that the more farmers plough (especially with tractors) the lower yield they get. But as we saw that the number of ploughings is related to bad soil structures, poor effects of ploughings on soil improvement could be responsible rather than the ploughing itself.

IV.4.3. Fertilizers

Fertilizer's impact on final wheat yield is particularly hard to find. Because farmers mostly use fertilizer to enhance poor soil performances or belated sowing, fertilizer applications seem inversely related to crop yield as table 15 shows.

Farmers who want yields as high as possible seem to characteristically use DAP but inside this category, the quantity is not a criteria of high results since $R=-0.18$. SSP seems to have an effect on wheat density which is understandable since it is applied on saline field (see impact of salinity on wheat development). Potash and ammonitrate are not used on enough plots to be interpreted.

Table 15. Correlation between fertilizers and wheat yield.

Correlation coefficient R	Number of applications	Urea	DAP	SSP
Final yield		-0.25	0.25	
number of spikes per m2	-0.28	-0.27		-0.21
number of grains per spike				
weight of thousand grains	-0.3			
straw weight			0.3	

IV.4.4. Sowing

Data do not show any impact of sowing depth on wheat density, nor on final yield. Sowing doses seem to have an effect particularly on the weight of grains (R=-0.35). The higher dose farmers give the lower weight of grains they get. Similar effect seems to exist with straw weight (R=-0.23).

While data confirm that selected seeds improve the final yield it would be interesting to check if yield differences are due to variety itself or to the reasons that go with other choices made by farmers (equipment used for soil preparation, inputs, etc.)

IV.4.5. Rainfalls

Rain data are available for the four following watercourses Azim 63-L, Azim 111-L, Fordwah 62-R, Fordwah 130-R. Rain data for the 3 missing watercourses have been approximated to the closest watercourse's data. Rain from November 1st to April 28th have been considered, given that the harvesting period was over by that time.

Recommended doses for single water applications are 3 inches, i.e. 75 mm or 303 m^3 per acre. Maximum rain fall reaches 25 mm (94 m^3/acre) on Fordwah 130 during April, but on average rain falls bring 3.25 mm (12 m^3/acre), i.e. 25 mm less than the minimum recommended. For this reason, the signification of each rainfall remains limited. Indeed, single rain contribution can hardly be considered as influential, but total contribution is undeniable, as asserted by farmers. More importantly, rains delay irrigations for 10 days for most of the farmers, especially when they have infiltration problems.

Table 16. Rain data in mm and in m^3 per acre.

Watercourse	November		December		January		February		March		April		Total rain quantity	
	mm	m3/a	mm	m3/a	mm	m3/a	mm	m3/a	mm	m3/a	mm	m3/a	mm	m3/a
Azim 20-L, Azim 63-L	0	0	3	11	11	45	7	28	4	14	14	57	39	155
Azim 111-L	0	0	8	32	15	59	9	36	8	32	13	51	53	210
Fordwah 14-R, Fordwah 43-R, Fordwah 62-R	0	0	3	11	12	49	16	65	3	13	9	36	44	175
Fordwah 130-R	0	0	9	36	15	62	17	66	0	0	36	143	77	308

IV.4.6. Temperature

A correlation coefficient shows that delayed sowing date has a negative effect on wheat yield (R=-0.28), but it appears even more clearly when looking at the water diagrams shows the sowing date as one of the main yield limiting factor. Indeed, for early sowing, all kind of yields are obtained (which stresses up many other factors influence), but for late sowing, even with a global water amount superior to the recommended amount and applied at the right stages, it has been clearly shown that yield decreases in a irreversible way, because of climate associated effect. A significant example is summarized below.

Qazi Ali field number 173/11/7 received 11752 m^3/acre, which is approximately the quantity recommended, and irrigations should have given one of the best grain weight. Though, this field had the worst weight of thousand grains. This result shows up the importance of "high temperature effect" which affects wheat especially when it is sown late (see wheat cycle).

IV.4.7. Discussion

A selection had to be done among the theoretical factors having an impact on wheat yields. According to observations on the 56 plots, it was admitted that the date of sowing, seeds varieties and their origins, quantity of DAP, irrigation quantity and timing, and salinity were the most determinant for final wheat yields in Hasilpur area. Table 17 summarizes the impact of some of the variables analyzed in this study.

As discussed before, salinity is not directly acting on wheat growth, but is influencing indirectly the grow of the crop via its impact on water management activities.

Table 17. Main external factors supposed to have an impact, and their effects on wheat yield according to observations on 56 plots.

Factors	Effect	remarks
Sowing depth	No	
Sowing dose	No	plants competition if density is too high
Seeds origin/cultivar	Yes	may be partly made up by other considerations going with the choice of the variety
Date of sowing	Yes	determines the potential yield levels
Soil preparation	No	fails in improving soil performance
DAP	Yes	other considerations should be taken into account
other fertilizers	No	Tested separately. Made up by soil poor performances
irrigation	Yes	Yields depend on volumes but even more on the flexibility of the irrigations. Date of first irrigation is most determinant. More effect before anthesis. No impact of water quality.
Salinity	Yes	Farmers manage it well because of relatively low levels and adequate practices.
Temperature	Yes	could not be quantified
Rain	Yes	could not be quantified

For different combinations of these factors (combinations which determine the sequences defined previously), production functions have been developed and are presented in the following section.

IV.5. Production function analysis

The final output of the research is the development of a production function relating wheat yield and farming and irrigation practices. The main objective of this analysis was to estimate the marginal impact of changes in various practices on wheat yield (or gross value of production).

Regression analysis has been selected for this analysis. The analysis of the water-balance and of farming practices led to the identification of the (independent) variables that would have the highest expected impact on wheat yield (dependant variable).

For the water supply, the quantity and timing aspects of each series of irrigation events were integrated into a single variable, i.e. the water-balance at the critical stage of the crop growth expressed as the relative gap between available water and field capacity at the booting stage (correlation analysis was undertaken to identify the factors influencing wheat yields in the most significant way). The main independent variables used are listed below.

SOILTEXT	:	Soil texture, equal to 1 for sandy soils and equal to 2 for loamy clay soils
ETRD-B	:	Relative evapotranspiration at the booting stage of the crop, computed with the CROPWAT software
SOWDATE	:	Sowing date expressed in number of days after November 1 (optimum date as disseminated by the extension services in the area)
SDORIG	:	Origin of seeds, equal to 0 if the seeds have been purchased in the market and equal to 1 otherwise
QDAP	:	Total quantity of DAP applied (in kg/acre)
QUREA	:	Total quantity of urea applied (in kg/acre)
QSSP	:	Total quantity of SSP applied (in kg/acre)
QPOTSH	:	Total quantity of potash applied (in kg/acre)

The dependant variable was not the wheat yield itself, but the reduction in yield compared to the maximum yield as already used in the previous part of the present report (thus, the dependant variable does not have any dimension). The final results of the regression analysis (i.e. the parameters estimated for the different variables, and the statistical indicators characterizing the significance of each parameter) are displayed in the following table.

Table 18. Summary of results obtained from the regression analysis.

Variable	Parameter estimate	Standard error	T for Ho: Parameter=0	Prob > |T|
INTERCEPT	0.8903	0.0860	10.349	0.0001
SOILTXT	-0.1085	0.0317	-3.425	0.0014
ETRED-B	0.5238	0.1421	3.686	0.0006
SOWDATE	0.0056	0.0014	4.012	0.0002
SDORIG	-0.2140	0.0627	-3.412	0.0014
QDAP	-0.0043	0.0008	-5.320	0.0001
QUREA	-0.0013	0.0005	-2.472	0.0176
QSSP	-0.0013	0.0006	-2.021	0.0497
QPOTSH	0.0070	0.0016	4.289	0.0001

General statistical parameters

F Value	:	13.036
Prob > F	:	0.0001
R-square	:	0.7129
Adjusted R-square	:	0.6572

The very high R-square and adjusted R-square, along with the high level of significance of the different parameters estimated, highlights the relevance of the in-depth analysis of irrigation and farming practices for the selection of the appropriate independent variables.

As expected, the irrigation related variable (represented by the variable ETRED-B) and sowing date have a positive impact on the yield reduction, i.e. a increase in the water stress and a delay in the sowing increases the yield reduction, thus reduces the actual yield. Similarly, the coefficient identified for the main fertilizers (DAP, Urea and SSP) are consistent to what can be expected and shows a negative impact of an increase in fertilizer use on the yield gap, i.e. a positive impact on the wheat yield itself.

The sign of the coefficient before the Potash variable only is contrary to what could have been expected. The fact that two farmers only use Potash possibly to respond to specific conditions that have not been taken into account in the analysis could explain this unexpected negative sign.

As an example of the use of this production function, to use of purchased seeds instead of own seeds would increase wheat yield on average by 320 kg/acre. Similarly, an increase of the quantity of DAP used by 40 kg/acre (one bag) would yield to a similar increase of 320 kg/acre. To sow wheat one week earlier than the average of the farmers would lead to a gain of 100 kg/acre.

As a conclusion, it is important to note that the R2 obtained for this production function is very high, highlighting the usefulness of the approach where the results of an in-depth agronomic analysis are used as the basis to select the appropriate variables for the regression analysis and the identification of production functions. However, further analysis would be required regarding the most appropriate function to be used (quadratic for example regarding the impact of water and fertilizers). And the inclusion of proper variables describing salinity and sodicity in the different fields monitored.

The fact that the production function does not provide a straight link between wheat yield and irrigation water supplied (but a link between a yield reduction and a water balance variable) makes its use difficult for staff from extension services for example. This means that the form of the production function has to be modified and simplified to include more readily measurable variables regarding irrigation water supplies.

CONCLUSION

1. The originality of the approach used in this research consists of **starting from the plot level by studying the wheat yields and relating it to farmers practices** and progress **to the farm level by linking farmers' strategies to yields.**

Wheat cultivation studied in its global environment (crops rotation, soil, inputs, production level, percentage of the production sold, etc.) as a component of the total farm activities could therefore be partly explained by farmers' general objectives.

Another novel factor in this approach regarded wheat roots as neither local nor national agencies have studied the relationship between wheat yields, roots development and soil characteristics so far. Moreover, no data regarding the maximum potential depth in Punjab could be found in literature or during visits to local institutes. Although, literature insists on that point and investigations, even if they were led on four plots, showed the importance of relating crop development to soil fertility in the first horizons and to water circulation through the whole root profile. Therefore we assert that it is an important point to develop further.

Harvest procedure was seen as appropriate since yields obtained represented plot yields and figures were consistent both with local institutes' assertions and previous studies made in the area.

2. The method highlighted the **importance of restituting results to farmers**. This allows a comparison between farmer's perception and assumptions made during the study. Some rules could be partly surmised and discussed according to different scenarios, which reduced the gap between the interviewed and the interviewer. Lastly, it was the occasion to return to the farmers part of the results of the analysis by answering his questions or discussing recommendations with him. Indeed, observations of the practices led to some misunderstanding and opened dialogue for clarification. When discussed with the farmers, logic of the practices became more apparent in the context of general farmer's strategy. Some recommendations were discussed with well presented arguments. Anyway the purpose of the meetings was not to make farmers change their practices but to discuss with them and eventually test some suggestions. For that purpose, two specific tools were used :

- a schematic diagram of the season implemented with cards representing each kind of practice.
- a map of the farm total operated area, for spacial representation of the farm activities.

They allowed a more important participation of the farmer as different scenarios had to be simulated.

3. The main results of the study are summarized below.

Variability in irrigation schedule was either due to soil nature, rainfalls or other crop priority. Indeed, with wheat being grown mostly for auto-consumption, priority was almost always given to profitable crops when there was a water shortage.

Similarly to what Bhatti et al. found in 1989 in Punjab, farmers apply the first irrigation at least one week later than recommended, but total average quantity is not far from the 525 mm recommended by local institutes. Another difference is in the date of the last applications. Indeed, according to Bhatti et al. terminal irrigations are out off too soon, but here many farmers seem to delay them so they might increase the application from the middle of March to the beginning of April, which is too late. Nothing could justify this practice, which is never mentioned in the literature or by the local authorities. The high temperature hazards in March and April makes this practice even more inefficient.

Water efficiency is poor. Best yields are not obtained with the highest quantities and yields are more related to tubewell percentage (which is a sign of reliability of the supply) than to the total amount of water. In the literature, the frequency and the timing of each irrigation are as important as volumes given.

The use of higher amounts of water was characteristic of well-equipped farmers (owners of tubewells) whereas those having a quite satisfying canal delivery tend to give lesser amounts, avoiding lower quality tubewell water while expecting canal to open soon.

Variability in fertilizer applications was due to maximizing cash savings: farmers wait for the wheat to boot before applying the second and eventually the third application. That way they avoid spoiling inputs on poorly grown fields. But the delay it creates mostly makes the last application inefficient because nitrogen is not needed for wheat development after March. On the contrary, it may favor the inclination of the stalks which prevents the resources from migrating toward the grain at the grain filling stage. That point appears often in the literature but farmers do not seem to have grasped it yet.

Variability in the date of sowing was due to the intensive cropping pattern which gave the priority to cotton most of the time for profit reasons. Labor constraint was often a reason evoked as well. Large wealthy farmers are constrained by their total area under crop but compensate with high machinery level (tractor for land preparation, drill for sowing, labor). Average date of sowing is nevertheless too late and limits the potential yields whatever the subsequent practices. Literature insists that is one of the most determinant factor of the yields. The importance of delayed sowing has even been officialized in Indian Punjab. Farmers know it but are probably not conscious of the real losses it creates.

Even though salinity is not very high in this area, farmers use slightly different practices to deal with it. Less total water is applied and the number of applications are slightly superior. These results are apparently opposite to the literature instructions, but it confirms local research centers' assertions which states that salinity scarcely goes without sodicity in Punjab. For that reason, water infiltration is decreased and soils suffer from water stagnation.

The rauni irrigation is proportionally larger than in non-saline fields obviously in order to leach salts, especially when canal water is still available. Specific inputs are used in particular Potash, SSP and gypsum. The first two confirm hypothesis on sodicity. Finally, special practices such as rotations, mentioned earlier, are used as well.

Variability in the crops rotations was directly dependant on farmers' objectives: cotton and sugarcane for those market-oriented farmers aiming for profit maximization, because they are most profitable;

fodder for those with a livestock strategy; rice and/or salinity grass for those with the main objective of land sustainability in saline/sodic zones; wheat for self consumption, eventually for extra benefits, the most representative crop of Rabi season.

From one author to another and depending on the country, literature stresses slightly different stages as being most critical. Using Cropwat, the most significant relationship between the relative yield decrease and the relative evapotranspiration deficit was found from the booting stage to the flowering stage. That stage was used subsequently to express the impact of factors on wheat yields.

The final output of the study was the production function. A highly significant relation was found since it explains 71 percent of the variability of the yield.

4. Finally, good communication between research centers and local agricultural institutes and extension services was observed, as recommendations and extension messages collected during visits were close to results of research institutes. These agencies recommend a sequence of practices well-known by the farmers, which is used as a reference by them, but which is scarcely followed exactly. Recommendations specifically adapted to a given set of constraints are not developed by research institutes nor disseminated by the extension services.

5. Nevertheless, if yields in Pakistani Punjab compared to Indian Punjab are 1.7 T/ha lower (Ayub Institute, 1995), farmers' practices alone cannot be held responsible. Indeed, agricultural policies are different in both countries as the following figures attest: tariffs for tubewell water are 12 times lower in India; **certified seeds** availability is 60 percent in India versus 8 percent in Pakistan; **fertilizer consumption** is also 1.5 times superior in India and the majority (75 percent) of the Indian farmers **sow early** whereas only 40 percent do in Pakistan; **Underground water quality** is also better and rainfall contribution is greater. These points are consistent with the selection of the most determinant factors of wheat yield made for the production function.

6. Limits of the study were identified and led to the conclusion that the work done here would have to be partly reconsidered once the currently missing data were available. Therefore, any assertion made in this report must be taken as hypothesis and will necessarily have to be confirmed. Still, the next steps of the program which this study belongs to can benefit from the following remarks:

Concerning the data:

- It is most important to calculating water quantities accurately. This means during the farmers' interview more accuracy must be given to the quantities attributed per plot. Indeed a global irrigation time was often attributed to a series of plots. There was no solution then except to give a proportional percentage of the total duration to each plot area, which was not necessarily true.

- Water paths and seepage rates must be reconsidered because they were only estimated (see text), which gives a large error margin.

- Soil analysis are available at IIMI, but it would be useful to give as well a codification to the soils of the sample farms according to their texture, in order to give them a more operational aspect. The same remark applies to the salinity data to be provided.

- During the data collection, ensure that the considered plot has been homogeneously practiced. If it is not, as it occurred many times in this campaign, each half would have to be treated as an independent field. These cases represent a particular interest as they often vary only by one or two factors. This gives then a more accurate idea of the impact of the factor on wheat yields since the others remain the same.

- As farming systems evolve continuously, special attention has to be paid to field areas, which vary from one year to the next. This parameter is most important in calculating the total depth of water applied and was source of error during this study.

- At least, in the farmers' interviews, a great attention should also be given to farmers' perception. For instance, talking about salinity with them often failed in these terms because they preferred to talk about poor soil performances, hard soils, and water stagnation. Therefore it is important to know their representation of factors we are trying to characterize.

Concerning the statistical interpretation:

- Once the basic data are more precise, their treatment will allow an even more significant elaboration and complex production functions, which should include salinity parameters in another way. Indeed, salinity has been included as part of the water balance parameters. However, salinity stress could not be distinguished from water stress at that stage. Thus separation of the two variables is required. Thus the most appropriate function to be used in different situations could be used.

- By running the linear regression 1-Ya/YM = Kc * 1-ETa/ETM, a specific crop coefficient will also be found to be used in simulation models as CROPWAT.

7. The existing typology has proven to be useful for understanding farmers' strategies and objectives, and therefore better insert wheat production inside the global farm system. However, as far as wheat is concerned, the 11 groups could be gathered in five main, determined by the similarities of their practices directly related to their objectives. It appeared also that variability within a group regarding wheat practices and yields can be sometimes quite important, as the selection of three farmers from the same group showed significant differences. We recall that the typology has been built on global farm characteristics and functioning and that wheat is only one of its components.

8. The present report focused on the wheat production as a contribution to total farm production and on farmers' practices related to this crop. The global view of the farm, seen as a system with its own rules, used in this study is still partial and should be complemented to understand farmers' strategies regarding water allocation between the different crops. Similar work on cotton is therefore starting this year and will allow the analysis of resource allocation strategies (for example the competition between wheat and cotton).

GLOSSARY

Drill	:	mechanical tool used for sowing in regular lines
Kachi rauni	:	when the soil is hard, farmers give few water, plough deep after three days to ease water infiltration, and then give Pakki irrigation
Kharif	:	is the summer season and it spans over six months from April to September. Cotton and rice are the main Kharif crops.
Kila	:	is a punjabi term for acre though both are slightly different in measurement : a kila is 220*220 feet while acre is 220*198 feet. A tract of land comprising 25 kilas is called a square or murraba (Siddiq, 1994).
Levelling	:	makes a flat soil, but removes a bigger amount of soil. Never used after sowing.
Mogha	:	is the point were canal water is transferred from main disty to watercourse.
Nakka	:	is a point on the farm field where irrigation water enters the field from the water channel.
Pakki rauni	:	higher water volumes given in good porosity soils
Planking	:	tool used to make a superficial flat soil. One of the purpose is to keep the soil moisture. It can be used either before or after sowing.
Rabi	:	is the winter crop season and it spans over rest of the six months (october to march). Wheat is the major Rabi crop.
Rauni	:	is a pre-irrigation which is applied after the field has been cleared from the previous crop and before proceeding for seed-bed preparation for the next crop. Sometimes, farmers use rauni irrigation before harvesting the crop, in order to save time for the next crop.
Warabandi	:	the canal water allocation schedule is called warabandi which means turn system implying that farmers take turns to use the canal later. in some areas, the turn revolves every seven days and in other every ten days. (Siddiq, 1994).
Wattar conditions	:	ideal soil moisture for sowing time, obtained 15 to 20 days after rauni irrigation

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