REPORT NO. R-31

Department of Irrigation and
Soil and Water Conservation,
Wageningen Agricultural
University.
Wageningen -The Netherlands

Centre National du
Machinisme Agricole du
Génie Rural des Eaux et des
Fôrets.
Montpellier -France

International Irrigation
Management Institute,
Lahore -Pakistan

RELATING FARMERS' PRACTICES TO COTTON YIELDS IN THE SOUTH-PUNJAB, PAKISTAN

P.D.B.J. MEERBACH

under the direction of:

Khalid RIAZ, IIMI Pakistan
Patrice GARIN, CEMAGREF Montpellier
and
Klaas ROSCHER, Wageningen Agricultural University

December 1995 - April 1996

FOREWORD

This report is the final report for the Master of Science Program of Mr. P. D. J. B. Meerbach in the Department of Irrigation and Soil and Water Conservation at the Wageinengen Agriculture University (WAU) in The Netherlands. He spent five months in Pakistan during 1996 to complete all of the necessary fieldwork and some of the analysis. The remaining analysis was completed during 1996-97 at CEMAGREF in Montpellier France and WAU Wagingengen, The Netherlands. This reproduction is identical with the document accepted by WAU during 1997.

We have a number of national and international students participating in the research program of the Pakistan National Program of the International Irrigation Management Institute. Their theses and dissertations are retained in our library for ready reference. Only a few of theses documents are selected for publication in our research report series. The principle criteria for publishing, is good quality research and topic that would be of interest to many of our national partners.

This report is an output of a collaborative research program with CEMAGREF, the French National research organization for agriculture, water and forests. However, this research is a part of our program under the project "Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan" funded by the Government of The Netherlands.

This research on cotton yields was preceeded by a companion study conducted during 1995 on wheat yields by Florence Pintus (IIMI Pakistan Report No. R-30). Both studies are focused on the agronomic practices used on a total of 56 fields (58 fields for cotton) of 14 farmers practicing a wheat-cotton rotation in southeastern Punjab. Statistical analysis was used to develop a production function expressing relative yield reductions for various farming cultural practices. Their report titles have been slightly modified to reflect that these are companion studies.

Gaylord V. Skogerboe, Director
Pakistan National Program
International Irrigation Management Institute

ACKNOWLEDGEMENT

This report is the result of the co-operation with many people and institutions. Without their contribution the realisation of this research would not have been possible.

Most of all I want to thank my supervisors, Khalid Riaz from IIMI Pakistan, who was of great value for the statistical analysis, Patrice Garin of CEMAGREF, who gave good support on the agronomic topics and the intra-farm water allocation and Klaas Roscher of the Department of Irrigation and Soil and Water Conservation, who helped me in finalising the agronomic analysis.
Along the way Marcel Kuper and Pierre Strosser of IIMI and Jos van Dam of the Department of Water Resources have been of great help.

Special thanks to the people Iworked together with at Hasilpur Field Station. Working and living with them was a very valuable experience and I could not have wished a better introduction into the Pakistani way of life. Their work in between the farmers and research institute itself and the knowledge they have build up in all those years of co-operation with the farmers has been of irreplaceable value to this research.
The fourteen farmers that I worked together with are the prominent actors in this report and though they might never read it I want to express my thanks for their co-operation and hospitality. I sincerely hope that one day their efforts for this research will be valuable for themselves.

I owe special thanks to Mr. Waheed Sultan Khan and Mr. A.G. Khan of Ayub Agricultural Research Institute Faisalabad, Mr. Khalid Gill of Soil Fertility Institute Lahore and Mr. M. Malik of the Central Cotton Research Institute Multan. Their knowledge of cotton cultivation was a great contribution.
Also Mr. Muhammad Bashir of the Hasilpur Agricultural Department and Master Aslam are thanked for this.

Last but not least there are a lot of people who's contribution to this report was indirectly by giving me a very good stay in Lahore. So, may all the IIMI employees, with whom I had a great time playing volleyball or cricket, may find my thanks here. Especially I want to thank Mr. Eric Benjamin, for keeping up the good spirit with me. Shabir and Mazhar for all the copying they have done and all the *chai* they provided. Mohsin, for all the motorcycle-related worries, Danyal and Moghis for their valuable care and our chowkidar at the Staff house and Ghulam Jaffar for maintaining my security.
Steven J. Visser is thanked for his wise decision to bury the conflict between civil engineers and agricultural engineers and giving good comments on the hydraulic aspects.
Of course, all the IIMI-students, especially Frank and Jane, thank you!

ABSTRACT

In this study farm characteristics and farmers practices are related to cotton yields in the Punjab, Pakistan. For this purpose data had been collected at 14 farms that represented farmers diversity in the Fordwah-Eastern Sadiqia irrigation system, concerning cultural practices at the field level.
The study started at the field level by analysing the sequence of activities that had been carried out at the cotton plots. This sequence of activities was compared with the recommendations on cotton growing activities provided by literature and Pakistani experts. In this way the major factors that influenced cotton yields in the area were identified. After a quantification of this factors for 58 plots of the 14 farmers statistical analysis was carried out. On that basis a production function was established which related relative cotton yield reductions to the waterstress during early flowering , the date of sowing, the sodicity of the topsoil, the timing of the first pesticide application and the total amount of nitrogen. The application of farm yard manure was an important factor, but data quality was too poor to allow insertion of this factor in the production function.
Farmers practices in the area show signs of intense cultivation.

- Irrigation water is always delivered to crops by means of tubewell water and, if available, canal water. Still, due to low canal water availability waterstresses occur at the majority of the fields. Also considerable overirrigation was observed in case water was available to the farmers. Therefore water use efficiency in the was in general low.
- Inputs, both fertilisers and pesticides, are used in considerable quantities and on almost all fields. Specific inputs used for land reclamation were not observed, because availability of these inputs is low.
- Almost all farmers use equipment like tractor, rotavator, drill and cultivator.

After this the study focused at the farm level. At this point farmers strategies were identified and the relations between farm characteristics and farmers practices at the field level were established. Three average sequences were identified in order to distinguish three main strategies: 1. *Intensification by high water consumption and high input consumption*, 2. *Intensification by high water consumption and low input consumption* and 3. *Extensification*. Via these strategies it was possible to relate cotton yields to farm characteristics. The analysis was extended to the water allocation within the farm, in order to analyse competition for water of different crops within the strategies.

PREFACE

This report is the result of a five month period at the International Irrigation Management Institute (IIMI) in Lahore, Pakistan. As part of my studies at the Department of Irrigation and Soil and Water Conservation at the Agricultural University of Wageningen I carried out a thesis research for the International Irrigation Management Institute in co-operation with CEMAGREF in Montpellier, France. IIMI is a non governmental institute, which main objective in Pakistan is to formulate recommendations in order to improve the performance of the irrigation system.
The research area of IIMI is the Chishtian sub-division, a sub-division of the Fordwah-irrigation system, and is located near the cities of Hasilpur and Bahawalnagar in the south of the Punjab, one of the four provinces of Pakistan. In this area research is carried out on topics ranging from hydraulics of the main canals to crop transpiration and from main canal management to farmers behaviour. Recently IIMI has attempted to integrate all the research efforts in one program, in order to develop a generic approach. This Integrated Approach is based on the modelling of a wide range of sub-systems of the irrigation system and decision making processes within the irrigation system.
This research has been carried out within the study at the farm and field level of the Integrated Approach. Its main objectives were to analyse cotton production, the main crop during the summer season, in order to create a cotton production function and to explain farmers behaviour in order to predict farm management and farm production regarding cotton. Also the results of the research were restituted to the farmers that were involved. The study used the data that had been collected during the cotton season. Most of the farmers practices were recorded and yield data had been collected for 60 fields. Also use was made of a farm typology, i.e. the distinction of 11 homogenous groups of farmers. This typology made it possible to relate farmers practices at the field level to their farm characteristics.
The study consists of three parts:

- An agronomic analysis of the impact of farmers practices on cotton yields. This agronomic analysis identified the main factors that determined the cotton yields.
- The establishment of a cotton production function to relate the cotton yield to the main factors identified in the agronomic analysis.
- The identification of farmers strategies by using the farm typology and the allocation of water to the different plots and crops within the farm.

List of figures

List of tables

List of units

Area	***Weight***	***Distance***
1 acres = 4047 m^2	1 trollee = 80 maunds	1 foot = 33 cm
1 square = 25 killas	1 maund = 40 kg	1 foot = 12 inches
1 killa = 3980 m^2		1 inch = 2.54 cm
1 killa = 8 kanals		1 m = 3.28 feet
1 kanal = 20 marlas		

Volumes	***Discharges***	***Miscellaneous***
1 $foot^3$ = 28.32 litres	1 cusec = 1 cubic foot/s	1 dS/m = 1 mmhos/cm
1 mm = 10 m^3/ha	1 m^3/s = 35.3 cusec	θ = volumetric soil moisture content
	1 cusec = 0.028 m^3/s	h = hydraulic head (cm)
	1 m^3/s = 1000 l/s	K = hydraulic conductivity

List of abbreviations

A.A.R.I.F.	Ayub Agricultural Research Institute
C.C.R.I.M.	Central Cotton Research Institute Multan
CEC	Cation Exchange Capacity
CEMAGREF	Centre National du Machinisme Agricole du Génie Rural des Eaux et des Fôrets
CIRAD	Centre de Coopération International en Recherche Agronomique pour le Développement
CNEARC	Centre National d'Etudes Agronomiques des Régions Chaudes
DAP	Diammonium Phosphate
EC	Electrical Conductivity
IIMI	International Irrigation Management Institute
o.m.	Organic matter
PIPD	Punjab Irrigation and Power Department
Rs	Rupees (Pakistani Currency, 33 Rs equals 1 US$, March 1996)
SAR	Sodium Adsorption Ratio
S.F.I.L.	Soil Fertility Institute Lahore
SIC	Simulation of Irrigation Canals
SODIC	Sodicity model
SSoP	Soil Survey of Pakistan
SSP	Single Superphosphate
SWAP93	Soil Water Air Plant 93
TUDELFT	University of Technology Delft
WAU	Wageningen Agricultural University

CHAPTER 1 INTRODUCTION

1.1 Irrigation in Pakistan

Pakistan in general

The self awareness was growing in the British ruled Indian Sub-Continent. In 1906 the Muslim League was founded to demand an independent Muslim state but it was until 24 years later that a totally separate Muslim homeland was proposed. Around the same time, a group of England-based Muslim exiles coined the name Pakistan, meaning 'Land of the Pure'. The *Islamic Republic of Pakistan* gained its independence on the 14th of August 1947, after centuries of British influence in the Sub-Continent.

Pakistan is bounded in the north by China, in the east by India, in the west by Iran and Afghanistan and in the south by the Indian Ocean. Roughly, the country is situated in between 22.5° and 35° latitude north, and in between 60° and 75° longitude west. For a map of Pakistan, see Figure 1.1.

The climate in the centre and the south of Pakistan (Sind, Baluchistan and Punjab) is dominated by hot and dry summers with temperatures up to 47°C, called the *Kharif* season and gentle winters with temperatures up to 25°C, called the *Rabi* season. In the north, the climate is more moderate due to local geographical differences of the Himalayan mountains (North-West Frontier Province and Jammu / Kashmir). With an annual rainfall of 300 mm a year, the potential evapotranspiration of most of the crops always exceeds the rainfall. Intensive irrigation, both gravity irrigation and tubewell irrigation, is necessary to meet the crop water requirements.

With a population of approximately 125 million and a total area of 887.700 km^2, the density of population becomes 141 inhabitants / km^2. Approximately 70% of the total population is situated in the centre of Pakistan (Punjab) along the main rivers of the Indus Plains. With a literacy rate of 35% only, a population growth ratio of 3%, and an average annual per capita income of $380, Pakistan can be defined as a developing country. In spite of the widespread poverty, Pakistan has the potentials to cope its problems with structural aid and investments in the industrial and agricultural sector. Pakistan economy is dominated by agriculture: 54% of the labour is active in the agricultural sector, which forms 26% of the Gross National Product (total GNP: $45.5 billion), and 80% of the total export value. The main agricultural cash crop is cotton.

The Indus system

Pakistan has one of the largest contiguous gravity irrigation systems in the world, situated mainly in the Indus Plain and river Kabul / lower Swat. The agricultural centre of Pakistan is situated along the 5 major rivers of the Indus system, and is called the Punjab [1] (*'five rivers'*). The development of the irrigation system in Pakistan and India started about 150 years ago, during British rule (van Essen and van der Feltz, 1992).

The *Indus Basin River Irrigation System* is fed by the Indus river and its major tributaries: Jhelum, Chenab, Ravi and Sutlej river. Three main reservoirs (Mangla dam, Tarbela dam and Warsak dam), 19 barrages (head works), 12 link canals and 46 main canals are supplying irrigation water to an area of 16 million hectares and serve about 90,000 tertiary units. The total length of main canals (branches), secondary canals (distributaries, minors and sub-minors) and tertiary canals (watercourses) is about 60,000 km.

After the independence of India and Pakistan, two rivers of the Indus system, i.e. the Sutlej river and

---

1 *With the inception of Pakistan, the Punjab has been divided into two parts: west Punjab (Pakistan) and east Punjab (India). West Punjab can be divided into two regions. The north-west dry hill region and the Indus plains, an alluvial and flat plain. It slopes are almost imperceptibly south-west. West of the Sutlej river, the land rises gradually and fades away into the Thar desert (Annual Report IIMI, 1993).*

the Ravi river, which are part of both the Pakistani and Indian irrigation system, resulted into a dispute on water rights. In 1960, the water rights were formally noted down in the Indus Water Treaty. According to this Treaty, Pakistan gained the rights of the three eastern rivers (Indus, Jhelum and Chenab), and India received the rights of the other two rivers (Ravi and Sutlej). The water of the rivers of the Indus system is fully utilised to the extend that in winter there is actually a shortage. To cope the shortage of water, especially of the Ravi and Sutlej rivers and in order to be able to distribute water of the rivers with a maximum advantage, the four rivers (Ravi, Chenab, Jhelum and Sutlej) have been linked by means of feeder canals or link canals.

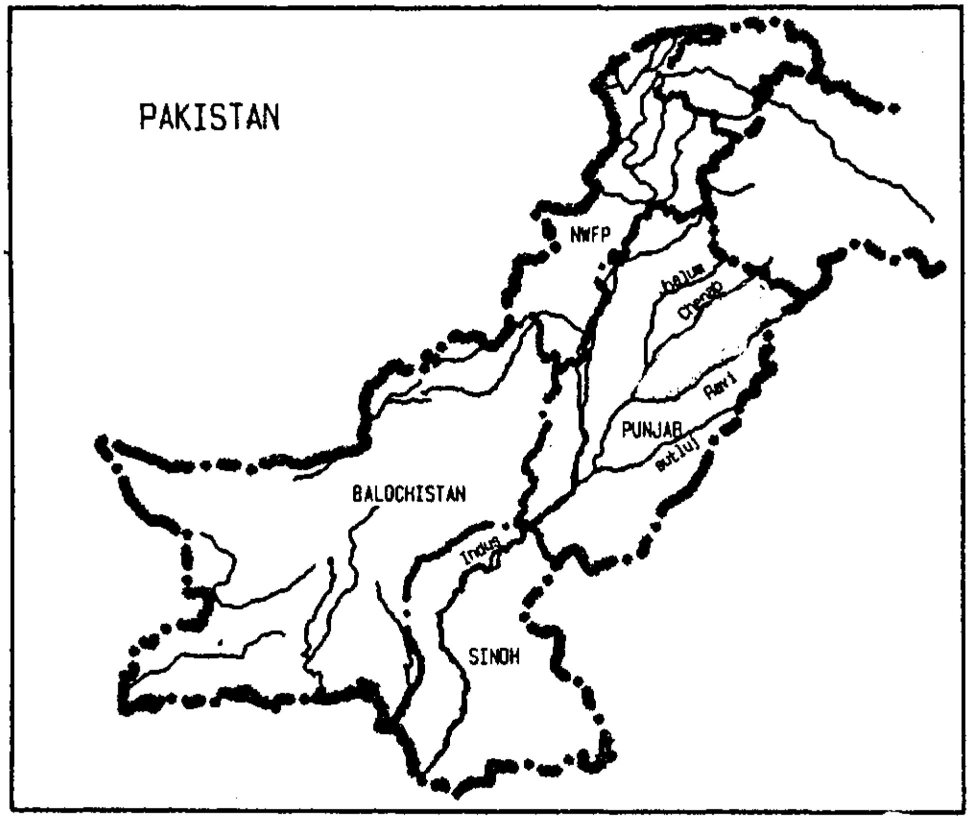

Figure 1.1. Map of Pakistan and the Indus and its tributaries (Ghassemi et al., 1995)

The physical layout of the irrigation system in Pakistan is based on a classical design approach, and based on protective irrigation management. In general, the classical layout of an irrigation system consists of two major components. The **main system** consists of the head works, link canals, the main or branch canals and main cross structure devices (cross regulators), the secondary canals (distributaries, minors and sub-minors), secondary off take structures and secondary cross structure devices. The **tertiary system** (tertiary unit, also referred to as watercourseconsists of 1 tertiary outlet structure, called the mogha, and corresponding tertiary canals (watercourses). Within the tertiary system a distinction can be made between the watercourses up to the farm inlet structure, called the nakkha, and the field watercourses. In Figure 1.2. the terminology of the Indus irrigation system is shown.

For operation and maintenance, the main system is under responsibility of the Punjab Irrigation and Power Department (PIPD) and the tertiary units are under responsibility of the farmers.

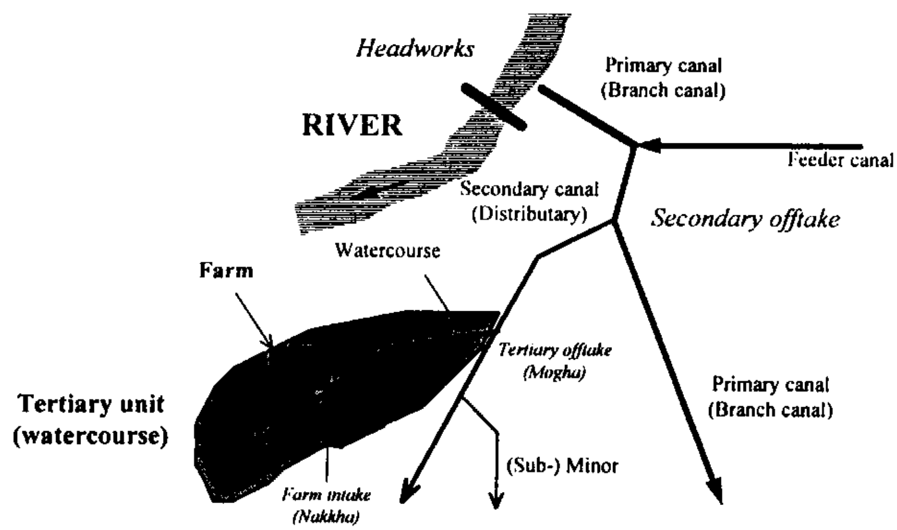

Figure 1.2. Terminology of infrastructural layout

Principles of water delivery

The hydraulic infrastructure of the system has been developed over the years. At present, the operation of the system is still based on the design principles of irrigation in the Indian Sub-Continent:

- The principle of **protective irrigation**. The available water is spread out over an area as large as possible.
- The principle of **equitable distribution** of canal water. The water is distributed equally over the area in such a way that each outlet structure receives an amount of canal water in equal proportion to the size of its command area, i.e. the same amount of water is distributed to every acre (supply-oriented).
- The principle of **proportional control** of canal water at the secondary level. The available water is distributed along the distributary to the tertiary units with fixed outlet structures that divide the flow into a fixed ratio. Besides a proportional distribution of a steady flow, a change in discharge at the parent canal is proportionally distributed along the outlet structures.

Problem identification

There are certain processes influencing the overall performance of present irrigation management in the Punjab, resulting in stagnant agricultural production (wheat, rice and sugarcane) and less sustainability overall. The main problems effecting the overall irrigation performance are:

The increasing demand of canal water supply due to intensified cropping patterns

1. The increasing demand for canal water due to an intensified cropping pattern.
2. Increase in saline tubewell water use, resulting in a negative effect on production due to increasing salinity and sodicity of the agricultural plots.
3. Sever waterlogging at the lower parts of the system due to bad drainage and intensive irrigation
4. Limited resources for proper maintenance and operation of the actual system by the PIPD
5. Non-technical problems due to political and social constraints resulting in water theft and illegal irrigation practices.
6. Inequity in water distribution, as shown by various studies (e.g. Kuper et al., 1994, Visser, 1996).

This is why the *International Irrigation Management Institute* [2] (IIMI-Pakistan), based in Lahore, Pakistan, has carried out research on inter-related issues of canal irrigation management, ground water extraction, agricultural production and salinity / sodicity since 1989.

1.2 Context of the study: the Integrated Approach

Introduction (after Kuper, Strosser, et al., 1996)
Low levels of agricultural productivity in Pakistan have long been associated with a low performance of the management (operation and maintenance) of the Indus Basin River Irrigation System, resulting in inequitable and highly variable canal water supplies along with environmental problems such as salinity, soil degradation and water logging (Bhutta and vander Velde, 1992; Kijne and Kuper, 1995). Recently, IIMI-Pakistan has made a start to integrate all their research components in the area of study [3] **in order to develop a methodology to evaluate the economic and environmental impact of (changes in) irrigation management**. Therefore it was decided to study irrigation from main system level to watercourse level and to farm- and field level, based on hydraulic, economical, sociological, institutional and agronomic aspects. This so called *Integrated Approach* is defined as an analytical tool to study the inter-relationships of irrigation, agricultural production and the environment at different levels of the irrigation system. The *Integrated Approach* will be based on two case studies (Kuper, Strosser et al, 1996)

1. Canal management interventions to mitigate salinity: evaluate the impact of interventions in canal irrigation management (at the main system level) on salinity / sodicity and agricultural production.
2. Water Markets Development in Pakistan: evaluate the technical feasibility of water market development and its impact on agricultural production and salinity / sodicity.

Initially, the integrated approach will be set up for the area of study, but finally, the approach will be generalised in order to study an *a priori* evaluation of management interventions and their environmental and economical impact of any irrigation system.

Research methodology (after Kuper, Strosser, et al., 1996)
An irrigation system can be represented in many ways. The representation adopted by IIMI is an intermediate position between two representations of an irrigation system:

- as *a technical bio-physical process* (Merkley, 1993).
- as *a place of collective and individual expectations of different actors that reflect power struggles within each social group* (Molle and Ruf, 1994).

Based on this two representations two visions are formulated, respectively, by IIMI-Pakistan.

---

2 *The International Irrigation Management Institute's (IIMI) mission is to strengthen national efforts to improve and sustain the performance of irrigation systems in developing countries. With its headquarters in Colombo, Sri Lanka, IIMI conducts a worldwide program to develop and disseminate improved approaches towards irrigation management. IIMI is an autonomous, nonprofit international research and training institute supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, World bank, United Nations Development Programme (UNDP) and more then 45 donor countries and private foundations (IIMI annual report, 1993).*

3 *The research has been concentrated on the Chishtian Sub-Division, an area of 67,000 ha irrigated sub-system, at the lower command area of the Fordwah main canal, in the south-east Punjab (more details: Description of the research area).*

- The process of water delivery by means of the hydraulic infrastructure has to be divided into different *sub-systems* by following the flow of water from the head of the main canal up to the farmer's fields.
- Irrigation is besides the hydraulic infrastructure an agricultural practice with many actors involved, leading to a complex *decision making process* concerning water management. Main actors that can be distinguished in the research area are the PIPD, the farmers community, and the individual farmer.

Within the *Integrated Approach* different sub-systems and decision making processes within the sub-systems are first schematised and modelled by analytical and decision making models and afterwards the models are linked with each other.
The main research themes for studying the sub-systems are hydraulics, economics and salinity and this is complemented by sociological, institutional and agronomic studies.

Four sub-systems are distinguished where study is carried out. A summary of this studies is presented in Table 1.1.

Study on sub-system 1: The main system

The main system, as it consists of the main canal and the corresponding distributaries, is studied for both the hydraulic state using a hydraulic flow model *SIC*: Simulation of Irrigation Canals, and the operational decision making process using the decision-making module *Gateman*. Both models are developed by CEMAGREF [4]. Using these models, both the canal water distribution within the main canal and distributaries, as the operational rules at the main canal (operations at the gated cross regulators and secondary off taking regulators) can be studied.

Activities:	*models SIC_{main}, SIC_{disty}, and Gateman (operational rules).*
Input:	*hydrograph at the head of the system (Suleimanki head works): $Q_{Head\ work}(t)$.*
Output:	*discharge at the head of the distributaries Q(t) and discharge at the head of the watercourses q(t), quantity and variability.*

Study on sub-system 2: The tertiary units

The canal water distribution within the tertiary unit is under responsibility of the farmers, who allocate the water according to a pre set warabandi schedule (further discussed in this chapter). The effect of the state of the watercourse and watercourse discharge fluctuations on the canal water distribution to the farms was studied using an analytical *hydraulic (volume-balance) model*. The rules determining the water allocation among the farmers are analysed in an *inter-farm water allocation model.*

Activities:	*Volume-Balance Watercourse model and Inter-Farm Water Allocation model.*
Input:	*discharge at the head of the watercourse q(t), quantity and variability.*
Output:	*discharge at the head of a farm $q_{farm}(t)$, quantity and variability.*

Study on sub-system 3: The farm

Farmers are taking the quantity and variability of canal water availability into account when planning their cropping pattern and input use (fertilisers, labour, pesticides, water, seeds). Eleven farm types are identified, to deal with the heterogeneity in farmers' strategies. The relations between available canal water supply, use of tubewell water, water trades in the area

4 *CEMAGREF, Centre National du Machinisme Agricole du Génie Rural des Eaux et des Forêts, the French research center for agricultural and environmental engineering, division Irrigation based in Montpellier, France.*

and intra-farm water allocation (based on plot potentials defined in terms of soil characteristics and location), are combined and studied using *linear programming (LP) models* for the different farm types.

Activities:	*Linear programming models and Intra-Farm Water Allocation models for the 11 farm types.*
Input:	*Canal water supply at the head of the farm q_{farm} (t), quantity and variability.*
Output:	*Cropping pattern, tubewell water use, intra-farm water allocation (water distribution to the fields, both canal water and tubewell water).*

Study on sub-system 4: The field

The use of different '*types*' of water with different qualities, i.e. the relatively good quality canal water and tubewell water of marginal quality (saline), are responsible for a complex process underlying the increase of salinity and sodicity in the area of study. To study the physical processes of water uptake of plants and the evolution of salinity, an analytical agro-hydrological solute transport model (*SWAP93*) will be used. The evolution of sodicity will be analysed by an initially developed deterministic approach (*SODIC*).

Table 1.1. Summary of thematic research studies, outputs and IIMI's collaboration

THEME	COMPONENT	OUTPUT MODEL	IIMI +
Hydraulics	- Main system irrigation management - Objectives / constraints of the PIPD - Maintenance and water distribution at the distributary level	- Integrated main system model (SIC $_{main}$ + Gate-man) - Distributaries (SIC $_{disty}$, simplified)	PIPD CEMAGREF TUDelft [5]
Economics	- Analysing farm systems - Farming practices and agricultural production - Intra-farm water allocation - Inter-farm water allocation - farmers decisions	- Farm typology - Production functions - set of rules - LP models - Aggregated watercourse LP models	CEMAGREF
Salinity	- Main issues related to salinity / sodicity - Analysing of physical processes - Farmers strategies related to salinity	- Agro-hydrological solute transport model (SWAP 93) - Predictive sodicity model (SODIC)	WAU SSoP [6] CIRAD[7]
Social and institutiona l context	- History of the irrigation system - Functioning of the PIPD - Factors influencing the water allocation within the tertiary unit - Political economy and irrigation management	- Social and institutional feasibility of management interventions	WAU CNEARC [8]

5 *Delft University of Technology, the Netherlands*
6 *Soil Survey of Pakistan*
7 *Centre de Coopération International en Recherche Agronomique pour le Développement*
8 *Centre National d' Etudes Agronomiques des Régions Chaudes, Montpellier, France*

source: Analysing large scale irrigation systems in an Integrated Approach, Kuper, Strosser et al, 1996.

In order to quantify the effects on agricultural output of farmers' management practices and irrigation practices and the impact of saline and sodic conditions, *production functions* for wheat and cotton have to be established.

Activities: *Modelling of salinity (SWAP93) and sodicity (SODIC) at field level. Creation of production functions for wheat and cotton.*

Input: *SWAP93: soil hydraulic parameters, canal water supply at the head of the farm q(t), quantity and variability, crop data, rainfall, potential evapotranspiration, water table depth; SODIC: soil type, present salinity (EC-value) and sodicity (SAR-value).*
Production functions: Management practices related to the farm typology.

Output: *SWAP93: actual and potential transpiration and evaporation, salt volume per layer soil (predicted EC-value); SODIC: predicted SAR-value.*
Yield levels for different farm groups.

Based on the presented scheme and the discussed models applied in the approach, different irrigation operation and maintenance scenario's at the main system level will be simulated, in order to evaluate the impact of irrigation practices on salinity, sodicity and agricultural production. For each scenario, a 10 year simulation will be used to be able to recommend different strategies to cope with the initial problems in the area. An example of the sequence of models as it is used within the Integrated Approach, applied to assess the impact of canal management interventions in the Chishtian Sub-Division, is displayed in Figure 1.3.

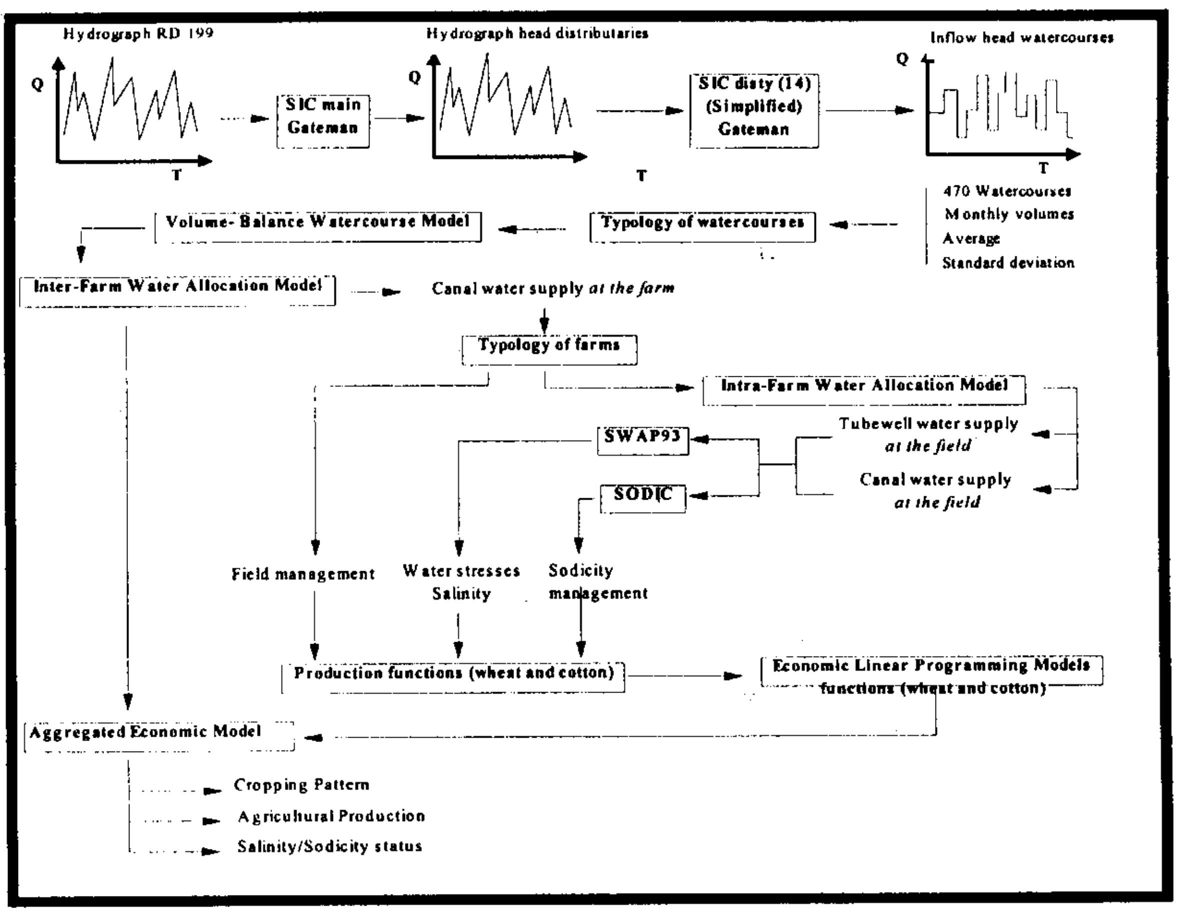

Figure 1.3. ***Schematic representation of the Integrated Approach applied to assess the impact of canal management interventions in the Chishtian Sub- Division.***

1.3 Objectives and approach of the study

This study was undertaken within the studies of *the farm and field sub-system* of the *Integrated Approach*. It succeeds a study conducted by Pintus, 1995, where the impact of irrigation, salinity and cultural practices on wheat yields was investigated. Three objectives were assigned to this study:

1. **To describe the relationships between cotton yields, farming practices, irrigation practices and salinity/sodicity at the field level in order to identify the main factors which determine the yield and to determine a production function to relate the cotton yield to these main factors.**

2. **To identify factors that explain differences in water allocation within the farm in order to develop a methodology to analyse water allocation strategies at the farm level for the whole cropping season and to understand farmers water allocation strategies for the Kharif season.**

3. **To restitute research results to farmers and discuss alternative strategies for improving agricultural production.**

The study was carried out among a group of sample farmers which were representatives for a farm typology. This farm typology was the result of a farming system analysis carried out by Rinaudo. This analysis and the selection of the sample farmers is discussed in paragraph 1.5.

For the *first objective* the factors that were important for the total cotton yield were identified by literature and information provided by agricultural institutions and experts in the region. Understanding was achieved about farmers practices by analysing the sequences of practices carried out at the field level. By these means the relevant factors were quantified for each field and statistical analysis was used to create a production function. To understand the production strategies of farmers, average sequences were deducted. The use of this average sequences within a farm and the way a farmer modified them could be related to their farm characteristics. So starting at the field level the analysis was extended in order to take into account the whole farm.

For the *second objective* the methodology was developed during the research for the first objective. Through observations done in the field and discussions held with farmers, the relevant factors to influence water allocation strategies within the farm were identified. The analysis focused at the water quantities applied to the crops and the impact it had on the crop transpiration. From this allocation priorities and constraints of the farmers could be identified and related to their overall farm-management. At the moment of writing this report the analysis has been carried out on 7 farmers.

For the *third objective* meetings were organised with each farmer were the results of the research were explained and alternative management was discussed. The restitution was carried out after the first objective was achieved. The restitution mainly served as a validation of the research results after the investigation for the first objective.

1.4 Description of the research area

The research was conducted on five sample watercourses, i.e. tertiary units, in the Chishtian sub-division, close to the town of Hasilpur. This sample watercourses are situated at RD 20 and 111 of

Azim-distributary and RD [9] 14, 46, 62 and 130 of Fordwah-distributary. Notation of this watercourses is for instance Azim 20-L or Fordwah 130-R. Both distributaries take of from the Fordwah-Branch. Azim is a non-perennial distributary, i.e. it does not receive water during the Rabi. Fordwah is a perennial distributary, so it receives water all year round.

The command area of the Fordwah-Eastern Sadiqia irrigation project is located in the south-east of the Punjab, Pakistan. It is bounded by the Sutlej River in the north-east, by the border with India in the east and by the Cholistan desert in the south-east. This study is part of the IIMI study conducted at the main system level of the Chishtian Sub-Division, part of the Fordwah Division. The system takes off at Suleimanki headwork, a large barrage on the Sutlej River, built in the 1920's by the British. Three primary canals take off from this barrage: the Fordwah and Easter Sadiqia Primary canals on the left bank, and the Pakpattan Primary Canal on the right bank. The Fordwah Division is divided in three Sub-Divisions: Minchinabad Sub-Division, Bahawalnagar Sub-Division and Chishtian Sub-Division (RD 245 to RD 371 of Fordwah Branch). The Fordwah-Branch has a total length of 123 km, with 38.4 km located in the Chishtian Sub-Division. The design discharge at the handover point of the Chishtian Sub-Division is 1282 cfs (36.3 m^3/s). A map of the distributaries and their command areas within the Chishtian Sub-division can be found in Figure 1.4.

Out of the 14 distributaries within the Chishtian Sub-Division, 9 are non-perennial, i.e. water is not received during the Rabi season, and 5 are perennial, i.e. water is received throughout the year. Besides surface canal water supply, increasing tubewell irrigation supply is used to meet the crop requirements. Almost all tube wells are in private use, owned by big farmers, or a group of farmers.
The farmers share the canal water supply among themselves through a flexible schedule of turns called *kacha warabandi*[10]. This system of warabandi was agreed upon by the farmers themselves, with the PIPD interfering only when a dispute arose. About 20 to 30 years ago, due to increased disputes about canal water supply at the watercourse level, the PIPD intervened in most of the watercourses and fixed an official schedule of water turns, *pacca warabandi* (*pacca = official*).

General features of the system (Kuper and Kijne, 1992)

The Fordwah-Eastern Sadiqia area covers 301,000 ha, out of which 232,000 ha are recommended. for cultivation. The climate is semi-arid with annual evaporation (2400 mm) far exceeding the annual rainfall (260 mm). Most of the rain fall occurs during the Monsoon period, between July and September. The highest temperatures occur during May and June (between 30 C° and 50 C°), and the evaporation rate is about 13 mm/day. The cropping pattern is cotton, rice and sugarcane in the Kharif season (summer flood season, 15th April to 15th October), and wheat and fodder in the Rabi season (winter
season, 15 th October to 15th April). This area is part of the Sutlej Valley Project undertaken in 1920's and completed in 1932. Both Fordwah and Eastern Sadiqia canals receive their supply from link canals since partition, as most part off the water from the Sutlej River is used by India. In Kharif the supplies are diverted from the Chenab river and conveyed through so called Link canals or feeder canals to the
Sutlej River. In Rabi the water comes from the Mangla Dam. Because supply in the winter season is very limited, irrigation canals are divided in perennial and non-perennial canals. Perennial canals receive their water the entire year, while non-perennial canals receive water only during the Kharif season.
Next page:

---

9 *1 RD = 1000 ft = 304.8 meters. It refers to the distance from the secondary off-take structure to the inlet of the tertiary unit, the mogha.*

10 *kacha = informal; wahr = turn, and bandi = fixed*

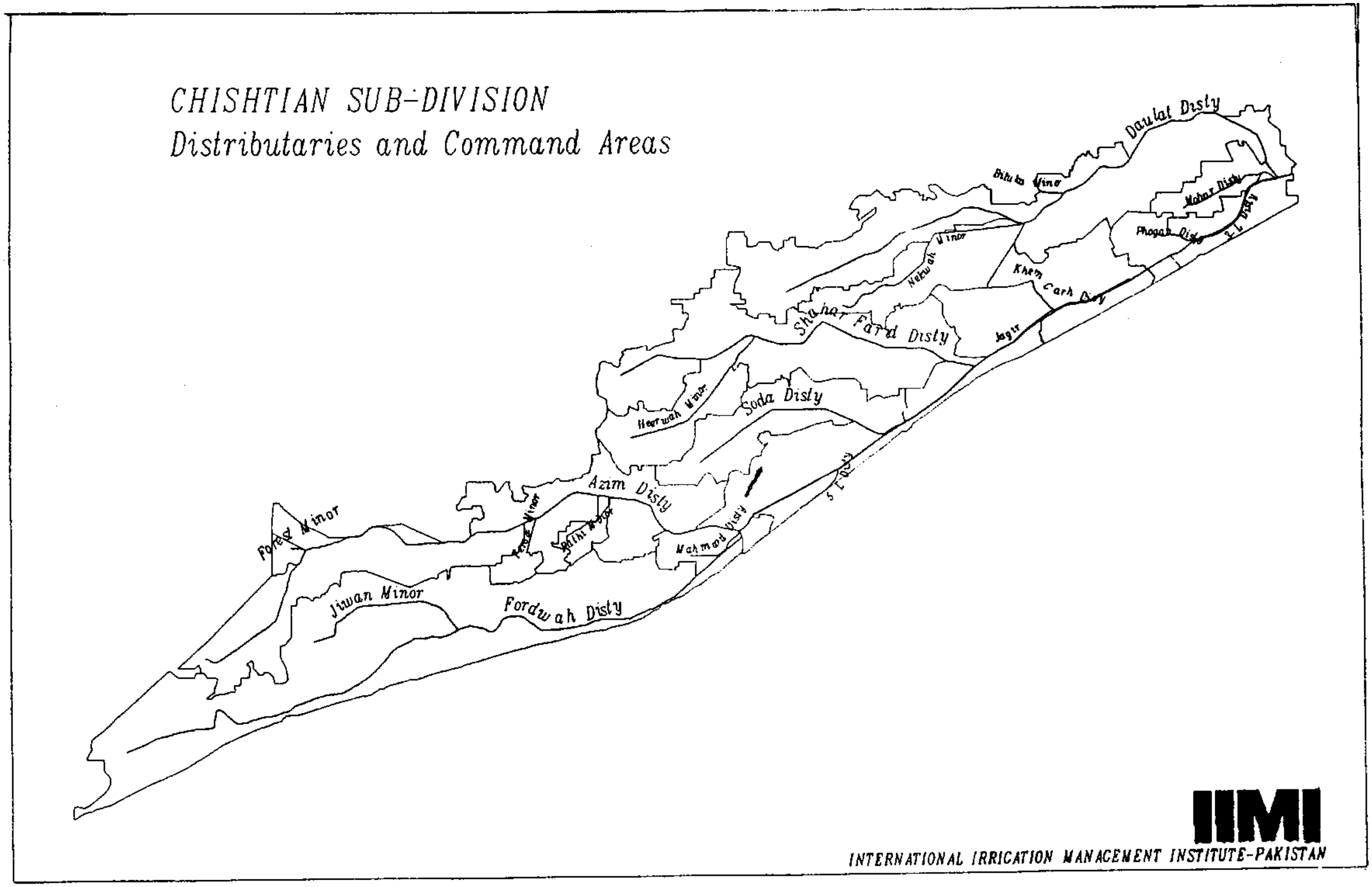

Figure 1.4. Map of the Chishtian Sub-division

1.5 Farming systems analysis and selection of sample farms

1.5.1 Typology (after Rinaudo, 1996)

As mentioned previous this research uses the results of a farming systems analysis which lead to a farm typology. This farm typology is the identification of homogenous groups of farmers, based on their characteristics. The main characteristics that were distinguished are the objectives, the constraints, the production strategies and the participation in water transactions (Strosser and Rieu, 1994). This division was based on the analysis of a socio-economic survey carried out in 1993 for 278 farms located on 8 sample watercourses. The 5 sample watercourses of this study were included in this survey.
In this survey an assessment was made of farm structure variables, i.e. the permanent production factors (land holding, machinery, livestock, cash availability and water supply), and of production variables, i.e. cropping pattern and production performance. Based on this assessment eleven homogenous groups in terms of production and water use strategies and farm objectives were identified in a study carried out by Rinaudo in 1994. The main characteristics of these groups are displayed in table 1.2.
The term *objectives* is understood in a socio-economic way as the goal of the production activities. For instance, objectives can be profit maximisation, land reclamation, market- orientated production or subsistence orientated production.
The term *strategies* is understood as the production rules that a farmer follows in order to achieve his objective. This production rules determine the allocation of resources to certain activities within the farm.

The 11 groups are divided into three according to their main production objectives. On one hand the market orientated groups, and on the other hand the groups whose objective is auto-consumption. The market orientated group is sub-divided into two groups whose strategy is diversification of crops, mostly rice and sugarcane included in the cropping pattern, and groups whose strategy is to cultivate mainly cotton in Kharif and wheat in Rabi.
A further sub-division is made according to similarities in the characteristics between groups.

- Market orientated groups

Groups 9, 10 and 11
Three groups 9, 10 and 11, are mainly composed of farmers with large landholdings and a good investment capacity. This is highlighted by the high level of mechanisation and the high percentage of private tubewell owners.

The main characteristic of **Group 9** is their sufficient water supply. The canal water supply is good and at the same time they are owner of a tubewell. For this reason water trading activities are expected to be a major source of income.
Another characteristic is the good availability of farm assets, like tractors and other equipment.
The factors which are supposed to be unlimiting are water, credit and household cash. The main production constraint is supposed to be land. Sugarcane represents some 12% of the total area cultivated in the Kharif.

The canal water supply of the farmers of **Group 10** is the smallest and the less reliable of all the farmers. Therefore the percentage of tubewell owners is high. Most of this farmers are located on Azim 111-L. This group is having many similarities with group 9, but their total operated area, their farm assets and their canal water supply is less. Rice is cultivated in response to a high percentage of fields affected by salinity, on average 33% of the total cultivated area. Also sugarcane is occupying about 10%. Therefore the area under cotton is limited.

Table 1.2. ***Main characteristics of farm groups***

Farm strategy	Autoconsumption			Market orientation							
				Wheat-Cotton			Diversified cropping pattern				
	Bad results	Inten sive cult	Exten sive cult.	Tenants			Small landowners limited credit		Large landowners, mechanised		
Group No.	1	7	8	4	5	6	2	3	9	10	11
Main watercourse	FW mid	FW mid/ tail	FW head	FW	FW tail	AZ mid	FW head	AZ head	FW head	AZ mid/ tail	AZ tail
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 (%)	9	17	20	17	11	20	5	11	50	50	92
Yearly cropping intensity (%)	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 (hours/ha)	25.4	62	24.5	37 4	58.3	63 8	10.8	25.0	4.4	2 4	9.7
Water sale (hours/ha)	2.5	9.7	3.1	0.8	0.7	8.2	1.0	2 5	33 3	26 0	8 7

Source: Rinaudo, 1995

Farmers of **Group 11** have a large investment capacity and large landholdings. This explains the high percentage of tubewell owners and tractor owners. A high percentage of the operated area is rented. Canal water supply is low and tubewell water is purchased in large quantities. Also a lot of water is being sold. Reason for this is the large size of the holdings. For fields far from their own tubewell water is purchased, for fields close to their tubewell not all the water is used, so that water is sold.
Water availability, so canal water and the costs of tubewell water, seems to be a constraint for the cultivation of sugarcane. Input consumption is high but yields stay moderate, probably due to the competition with sugarcane for water. Farmers of this group are highly market orientated.

Groups 4,5 and 6
Groups 4,5 and 6 are composed mainly of tenants. This is highlighted in the low percentage of owned land. Also this groups are characterised by the low percentage of tubewell owners and the low availability of farm assets.

Groups 4 and 5 are very similar to each other and are both similar to groups 1 and 2. Farms are small and the percentage of tubewell owners is low. This groups rely on canal water for the irrigation. The main differences between group 4 and 5 is the high percentage of land that is hired in and the yield level. Yields for cotton and wheat are low for Group 4. This is probably due to low fertility of the soils.
Yields for Group 5 are remarkably higher. Their cropping intensity reaches 160% and the quantity of purchased water is twice as high as the quantity of Group 4. Most of the farmers of Group 5 are located on Fordwah 130-R.

Group 6 is mainly composed of tenants operating medium sized landholdings. Farm assets are very low, with few tractor and tubewell owners. Canal water supply is bad. So agricultural production is fully dependant on purchased tubewell water. Therefore few crops with a high water requirement like sugarcane and rice are grown. Number of irrigation, level of input consumption and labour remains low.

Groups 2 and 3
Groups 2 and 3 are composed of farmers with a good canal water availability. This farmers are localised on the upstream watercourses of the distributaries. The good canal water supply is reflected in the cropping pattern in the presence of rice and sugarcane, crops with a high water requirement.

Group 2, like group 1, is characterised by a low level of capitalisation and the small total operated area. Canal water delivery is good. Difference with group 1 is the high percentage of area under sugarcane and a lower cropping intensity. The sugarcane is grown because of 2 reasons: 1. illegal pumping is assumed to increase the water availability 2. the proximity of a sugar mill. House-hold cash may be a major constraint which could keep yields low. Low percentage of tubewell and tractor owners.

The farms of **Group 3** are medium sized. Canal water availability during Kharif is good. The low level of machinery is compensated by a high number of oxen and a good availability of family labour. Access to tubewell water is good, either by purchasing water or owning a tubewell.
Sugarcane is cultivated at a high percentage of the total operated area. Reasons for this are the same as for group 2; illegal extraction of water and the proximity of a sugar mill. House hold cash does not seem to be a major constraint, probably due to family sending remittances.

- Auto-consumption orientated groups

Group 1, like group 2, is characterised by a low level of capitalisation and the small total cultivated area. The percentage of tubewell and tractor owners is low. Canal water delivery is good. The difference with group 2 is the cropping pattern. The area under wheat, cotton and fodder is high for group 1 and sugarcane represents a very small part of the total cultivated area. The access to tubewell water is low since cash availability is a major constraint.

Group 7 is composed of farmers who are operating a small total cultivated area. The strategy used for reaching the objective of auto-consumption is intensification, as is stressed by their high cropping intensity (178%). The farm assets are low, except tubewells, about 54% of the farmers owns a tubewell, most of them jointly with other farmers. Most of this farms are situated at the head of their respective watercourses, which assures a good canal water supply. Water is mostly allocated to wheat and cotton, which occupy 68 and 64 percent of the area in the Rabi and Kharif.
High quantities of fertilisers and chemicals assure good yields, but due to the big family sizes, 8.5 members on average, little of the yield is sold.

The main characteristic of the farmers of **Group 8** is the large family size (17.3 on average). Most of this members work outside the farm and therefore the main source of income is not the farm itself. Due to this land use is extensive, even though the farm sizes stay rather small.
The canal water supply is not good and reliable, and also the percentage of tubewell owners and amount of purchased tubewell water is low. Fertiliser and chemical quantities are low.
An important constraint faced at this farms, which depresses yields, is the area with salinity features, about 47% of the area on average.
The objective of this farms is to achieve with a minimum of inputs enough yield for auto-consumption and not to maximise their income with farm outputs, since that is done by the work outside the farm.

1.5.2 Selection of farms and sample fields

From this typology 11 farms, being representative for 9 groups, where selected for the monitoring of farmers' practices during Rabi '95. This selection was done by excluding farmers with a cropping pattern deviating much from a wheat-cotton rotation, since the main interest was in these crops. In addition to this, 4 farms were monitored on farmers practices and salinity/sodicity, with more plant specific data, i.e.

soil cover, number of plants, crop components, and soil specific data, i.e. profile analysis, tensiometer readings, Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR) measurements, available. This data were used for the calibration of the SWAP93-model.
At the end of Rabi 95, Pintus started conducting the research on farmers practices during the Rabi season. When the data collection on yields started, it appeared that one farmer had already harvested all his fields. So this left 14 sample farmers in total.
Pintus decided to collect yield data for 62 fields only, since no more time was available. This fields were also harvested for this study.
For several reasons 6 fields had to be dropped from further analysis in the production function. Reasons for this are that no water data were available or that the management practices on one field were different for two parts within that field. Also 2 sample fields which were treated separately in the Rabi season were treated the same this year. For two fields it was not clear how the yield was achieved. This leaves 56 fields in total.
The main characteristics of the farmers and the fields that have been selected are scheduled in table 1.3.

1.5.3 Limitations of the selection

First limitation is on the side of the sample farmers and the typology itself. At some points the classification does not seem logical. For instance, the distinctions between the groups are not always clear and the definitions that are used for land owners are vague. Also the farmers that are selected can not be considered fully representative for their group.
Second limitation is on the side of the sample farms. Only eight groups of the typology are represented by the 14 farms, leaving group 7, 8 and 5 without representors. The character of the practices of this groups have to be extrapolated from the information obtained from the other groups.
Third limitation is on the side of the sample fields. The distribution of the sample fields over the different groups and the different watercourses is not equal. For instance, 37 of the 62 fields were situated on the tail end of the system, Azim 111-L and Fordwah 130-R, were only five were selected at the head end, Fordwah 14-R and Azim 20-R. Also 14 fields were selected from group 9 only.

Table 1.3. Main characteristics of selected sample fields and sample farmers

Group	Farmer	Watercourse	Total cultivated area (killa)	Rented in (+) or out (-) area (killa)	Number of Sample fields (killa)	Total sample field area (killa)
Group 1	Bashir Ahmad	Fordwah 62-R	13.63	+6.25	2	1.5
Group 1	Muh. Siddique Haleem	Fordwah 62-R	5.45	0.0	6	3.0
Group 2	Shakar Ali	Fordwah 14-R	3.3	-0.8	1	1.25
Group 3	Muh. Irshad	Azim 20-L	10.75	0.0	5	4.0
Group 4	Muh. Youssaf	Fordwah 130-R	10.15	+6.0	7	5.65
Group 4	Abdul Sattar, ID 267	Fordwah 130-R	7.4	5.1	2	1.25
Group 6	Abdul Sattar, ID 208	Azim 111-L	7.32	+4.6	2	1.25
Group 9	Barkat Ali	Fordwah 62-R	5.5	-4.4	4	2.75
Group 9	Haji Elahi Baksh	Fordwah 46-R	10.1	+5.0	4	4.0
Group 9	Muh. Yaqoob	Fordwah 130-R	19.4	0.0	10	9.0
Group 10	Muh. Nawaz	Azim 111-L	17.8	+17.8	2	2.0
Group 10	Ghulam Hussain	Azim 111-L	10.6	+4.0	4	4.0
Group 11	Qazi Muh. Ali	Azim 111-L	21.75	- ±22	3	3.0
Group 11	Muh. Islam	Fordwah 130-R	31.4	+18 share cropped	8	6.5

This is having limitation for the representativity of the results for the Hasilpur region. Therefore none of the results of this report should be taken as an average for the region.
For the production function this is not having any limitations, since for this the variability in practices at the field level is concerned.

1.6. Organisation of the report

First the methodology of the study will be elaborated in Chapter 2. In Chapter 3 a comparison is made between the information obtained from the literature and the Pakistani research institutes about the way to grow cotton and the actual practices that are used in the Hasilpur area. In this chapter the actual agronomic analysis takes place.
In Chapter 4 the production function is presented, being a result from the agronomic and the statistical analysis. The major factors explaining cotton yields get revealed here.
Chapter 5 makes use of the results from the production function in order to select three average sequences used by the researched farmers. This sequences are related to the farm typology. Also in this chapter the intra-farm water allocation of the farm types are discussed.
Conclusions of the report are mentioned in Chapter 6.

CHAPTER 2 METHODOLOGY

2.1 Data collection procedure

2.1.1 Available data

In table 2.1. a list is displayed of the available data, the sources and the limitations. In a few cases assumptions had to be made in order to perform the analysis and also these are mentioned.

Table 2.1. Available data

Subject	Available data	Source	Limitations	Assumptions
Farmers' practices	Irrigation practices	Hasilpur FS	Often irrigation duration noted for a group of fields	Irrigation duration equivalent to plot area
	Labour use	Hasilpur FS	Often labour duration noted for a group of fields	Labour duration equivalent to plot area
	Input consumption	Hasilpur FS	No farm yard manure, no application method	Collected
	Machinery use	Hasilpur FS	Often machinery use duration noted for a group of fields	Machinery use duration equivalent to plot area
	Yields	Hasilpur FS	Some unreliability's, no components	
	Field and Crop Survey	Hasilpur FS	No clear definitions, only in September.	
	Necessary additional information	Interviews	With field assistants.	
Farm characteristics	Farm maps	Hasilpur FS	No field boundaries	Collected.
	Farm assets for 1993	Hasilpur FS	Changes in characteristics due to time between data collection and research.	
	Cash and credit availability for 1993	Hasilpur FS	-do-	
	Typology Description	Jean-Daniel Rinaudo	-do-	
	Soil Data	Soil Survey Pakistan	Established at watercourse level and different from farmers' statements.	Extrapolated to field level
	Soil Data	Expert Farmer	No clear definitions	
Water availability	Discharge at the mogha, determined 6 times a week	Hasilpur FS	Irrigation recorded at days with 0-discharge. Some missing days.	Average discharge of day before and day after
	Distance from Mogha to nakkha	Watercourse maps		
	Seepage rates	J.P. Barral and F. Pintus		
	Distance from nakkha to the plot	Had to be collected		
	Tubewell Discharges and Quality	Hasilpur FS		

2.1.2. Monitoring of farmers practices

The monitoring of farmers practices has been done by the field staff at the field station in Hasilpur. Every day of the week the farmers were interviewed about the practices they had performed the day before. Notations were made of their irrigation practices, labour activities, machinery use, input consumption and harvested quantities. Main limitation was the fact that most of the practices were noted for a group of fields, which was especially a handicap for the irrigation timing of each field. The assumption was made that the amount of water was equivalent to the area of the field and that losses due to filling time of the field watercourses could be neglected.

An other limitation was that a clear definition of practices was missing. What one field assistant would call a hoeing, the other would call a ploughing, the third would call a weeding. Therefore at a certain moment the only distinction made was between manual labour, oxen labour and machinery labour.

2.1.3 Collection of yield data

At the end of September 1995 the farmers started picking the cotton. For the 61 sample fields the cotton pick was observed by the field assistants. Agreements were made with the farmers to keep the yields of the sample fields separate from the other fields, since it is the custom to pick all the fields at the same time. In a few cases the lady pickers were paid to do this. After the picking the weight of the seedcotton was determined before the share of the pickers was deducted. In case a picking could not be observed the yield was measured afterwårds. Then an assumption had to be made about the share of the yield which was given to the pickers.
The picking ended most of the time by picking the closed cotton bolls which remained on the stem. This cotton bolls were stored separately form the other fields. After opening the weight of the cotton of this bolls was determined.
Main limitation of the yield data is that the yield is not separated into different components (bolls weight, seed weight, dry matter yield). Collecting this for 61 fields would have been too time consuming and expensive. In literature there are several relations mentioned between water and input stresses on one hand and the production of a certain crop component on the other hand. This relationships can not be elaborated now. The picking data are mentioned for each farmer in Annex 7 to 20, integrated in the technical sequences.

2.2. Sources of information

2.2.1. Literature

A lot of literature on cotton in general and cotton in Pakistan is available. Still the major source of information was interviews with Pakistani experts, since the majority of the literature is dealing with specific situations valid for a certain region. In the USA, Grimes, El-Zik, Krieg and Bartee, Joram and Frisbie wrote various articles about the characteristics of cotton, input and irrigation requirements and crop production functions. In Pakistan the various research institutes published on specific needs for irrigation supply and input consumption for the varieties used in the region.

2.2.2. Interviews

To obtain knowledge about cotton in the region four research institutes and one farmer, Master Aslam, known as an expert in the Chishtian sub-division, were interviewed and asked for their recommendations and the reasons behind this. The format of the interviews was semi-structured. These institutes were;

- Extension Service Hasilpur
- Ayub Agricultural Research Institute Faisalabad (A.A.R.I.F.)
- Central Cotton Research Institute Multan (C.C.R.I.M.)
- Soil Fertility Institute Lahore (S.F.I.L.)

With the information obtained from this institutes a good insight was achieved in the requirements of cotton and the practices required to grow it.
See Annex 1, 2, 3 and 4 for an elaboration of the interviews.

2.3. Analysis of Technical Sequences

From the data collected on farmers' practices a technical sequence was created, i.e. a chronological summation of all the activities carried out at the field level which could influence the cotton yield. A classification was made for the cotton yields to asses the relative amount for each field (see Annex 6). For the technical sequences of the 14 farmers, see Annex 7 to 20. With the information obtained before it was possible to analyse the farmers' practices and to comprehend in what way the cotton yield was achieved.

The analysis was divided in two parts:

1. An analysis of the cultural practices, i.e. labour, inputs, sowing, picking and harvesting dates.
2. Analysis of the irrigation practices by means of the SWAP93 - model.

2.3.1. Analysis of Cultural practices

The cultural practices were examined on 4 aspects: 1. the nature of practices, 2. the timing of practices, 3. the sequence of practices and 4. the amount of practices in relation to different crop stages. A classification was made in order to estimate the relative amount of inputs, labour and sowing dates (Annex 6). Also soil characteristics were taken into consideration.

2.3.2. Analysis of irrigation practices by using the SWAP93 model.

SWAP93 (Soil Water Air Plant 93)is an one dimensional agro-hydrological model which calculates the water and salt balance of the soil profile. It is a deterministic model, i.e. the physical laws are used to derive the relations between the relevant variables. SWAP93 is originating from the SWATR (Soil Water Actual Transpiration Rate)- model developed by Feddes et al. (1978) in order to describe transient water flow in a heterogeneous soil-root system under the influence of groundwater. Afterwards this model has been extended by Belmans et al. (1983) with different boundary conditions and by Van Dam (1991) with the possibility to simulate solute transport. The Working Group SWAP (1993) extended the model by including for example hysterisis, i.e. a changing h(θ)-relationship due to wetting or drying of the profile, according to the concept of Kool and Parker (1987) and the concept of preferential flow (Van Dam et al., 1990)

In SWAP93 the soil water flow is calculated by combining Darcy's law with the principles of mass

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left[K(h) \left(\frac{\partial h}{\partial z} + 1\right)\right] - S(h)$$

conservation, yielding to the Richard's equation:

where:

θ	=	soil moisture content (cm^3/cm^3)
t	=	time period
h	=	pressure head (cm)
S(h)	=	root water uptake (l/day)
K(h)	=	unsaturated hydraulic conductivity
z	=	height, positive upwards, origin at the soil surface (cm)

To solve this equation the soil hydraulic functions. i.e. the h(θ) and the k(θ)-relation, should be known. In SWAP93 this relations are determined by the Van Genuchten-Mualem (VGM) parameters.

The model consists of an input file, an execute file and an optional number of output files. The output file used in this case were the fluxes of the profile, so the cumulative transpiration, evaporation,

precipitation and irrigation, bottom boundary fluxes and the salt fluxes. Calibration of the model in the Chishtian sub-division was done by Smets, 1996, on the four fields with more detailed information. This fields represent the different soil types in the region.
In the calibrated model use was made of the concept of preferential flow. This was done since at the four fields a leaching was applied and at the same time the total amount of salts in the profile was increasing. Therefore it was assumed that there was a certain amount of immobile salts which could not be leached out due to preferential flow of the water in the profile. A side effect of this assumption is that also an irrigation application efficiency was simulated, since not all the water used is infiltrating homogeneously in the rootzone. The flux from water out of the rootzone, due to evapotranspiration or percolation, might be estimated higher by this concept.
Factors that were taken into account for the sample fields were:

1. **Soil type** For this use was made of the four calibrated models of IIMI. A classification was made of four soil groups and each of the 61 sample fields was classified according to its characteristics.
2. **Potential evaporation and transpiration**
- Evapotranspiration calculated by Penman-Monteith formula.
- Soil cover.
- By means of soil cover a distinction was made between E_{pot} and T_{pot}, according to the equation:

$$T_{pot} = Soil\ Cover * ET_{pot}$$

3. **Preferential flow**
4. **Groundwater table**
5. **Root water uptake characteristics**
- Rooting depth over the growing season
- Root distribution
- Sink terms for cotton.
6. **Irrigation and precipitation.**
7. **EC of irrigation water.**

A problem that was faced while working with the model was the fact that there was an interest not only in the actual transpiration of the crop but most of all in the ratio T_{act}/T_{max}. The potential transpiration of the crop depends on the soil cover and from the field and crop survey carried out in September (see Table 2.1. Available data) it appeared that not all the fields had an optimal soil cover. Therefore at first a classification was made of the soil cover, i.e. a percentage of the maximal soil cover for each sample field. By this means the T_{pot}, the maximal transpiration given the monitored soil cover, was estimated as an percentage of T_{max}, the maximal transpiration given a maximal soil cover. After the first runs it appeared that the actual transpiration was going towards the value of the T_{pot} and therefore the ratio T_{act}/T_{max} was going towards the classification, i.e. if T_{pot} was 75% of the T_{max}, due to a difference in soil cover, also T_{act}/T_{max} became 75%. This mend that the density of the field was a more determining factor for the T_{act}/T_{max} than the irrigation water application.
Since the production function has to be used within a generic approach (the *Integrated Approach*) it is not possible to asses the soil cover for all the fields which will be modelled, so it was decided to assume that all the fields were having a T_{pot} equal to T_{max}.
A negative effect of this is that in case of overirrigation by the farmer the T_{act} will be over estimated due to an overestimation of the T_{pot}.
The main output of the model the T_{act}, which made it possible to asses the waterstress, i.e. the ratio T_{act}/T_{pot}. This ratio was plotted in a graph to asses the waterstresses for each sample field over the

growing season. See Annex 7 to 20 for these graphs. The waterstresses were used in the production functions.
Since the output of the model was not conform the remarks of the farmers a sensitivity analysis was done on some components. The main problem was that in general the model was simulating waterstress when at the same time the farmers applied water much in excess to the crop water requirement.
Three possible causes were identified for an analysis:

1. Too low soil water retention capacity.
   - Van Genuchten-Mualem parameters.
   - Preferential flow.
2. Too little root uptake.
3. Too little capillary rise.
4. The influence from salts.

The results were:

1. Modifying the VGM-parameters according to the classification made by Wösten, showed a strong increase in the soil water retention capacity and gave a strong reduction in waterstresses. See Figure 2.1a and Figure 2.1b
   Also the soil water retention capacity was increased by eliminating the concept of preferential flow. In this case waterstresses in a given period could decrease with 10 to 15%. See Figure 2.2.a and Figure 2.2.b
2. An increase in root water uptake according to the values given in literature did not have an considerable impact.
3. First the assumption was made that a groundwater table below 250 cm from the surface would not have any impact. Taking into consideration groundwater tables up to 300 cm did not have any considerable impact.
4. Neglecting the salt influences did not show any differences.

2.4. Validating the analysis of technical sequences

For several reasons a validation was done by restituting the research results to the sample farmers.
Since IIMI has been collecting data already for a long time in the sub-division and the farmers never received any concrete information in return for the information they provided IIMI, the farmers have developed some ambiguous feeling about the work that IIMI does and the time and effort the farmers have to put in themselves.
IIMI started realising that it was necessary to develop some understanding among the farmers about the work IIMI is doing and that it would be good to offer the farmers some information about the impact of their practices, which IIMI could provide with the results obtained form the research in the region.
Also a restitution of the results could provide IIMI with a feedback on the results of their research.

For this reason it was decided to restitute the results of this research done to the 14 sample farmers which were monitored for this study.
The purpose of this was:

1. To validate the research results of the analysis of the technical sequences by obtaining feedback from the farmers through an open discussion.
2. To inform the farmers about the analysis that had been done, using the information that had been collected.at their farm, in order to make clear to the farmers what IIMI was doing with the information obtained and to create some understanding among the farmers of the activities of IIMI.
3. To discuss alternative practices that could improve farm cotton production.

At the moment of writing this report, restitution had been done to four farmers.

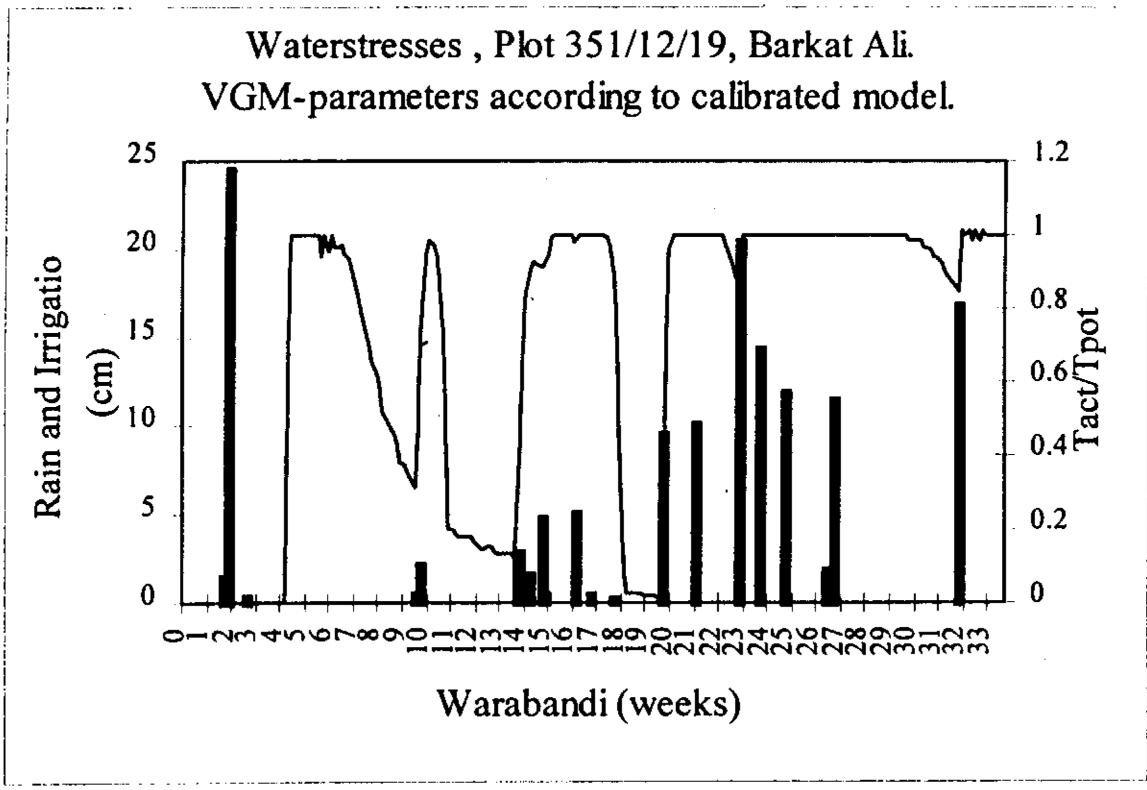

Figure 2.1.a. Waterstresses with VGM-parameters according to the calibrated model.

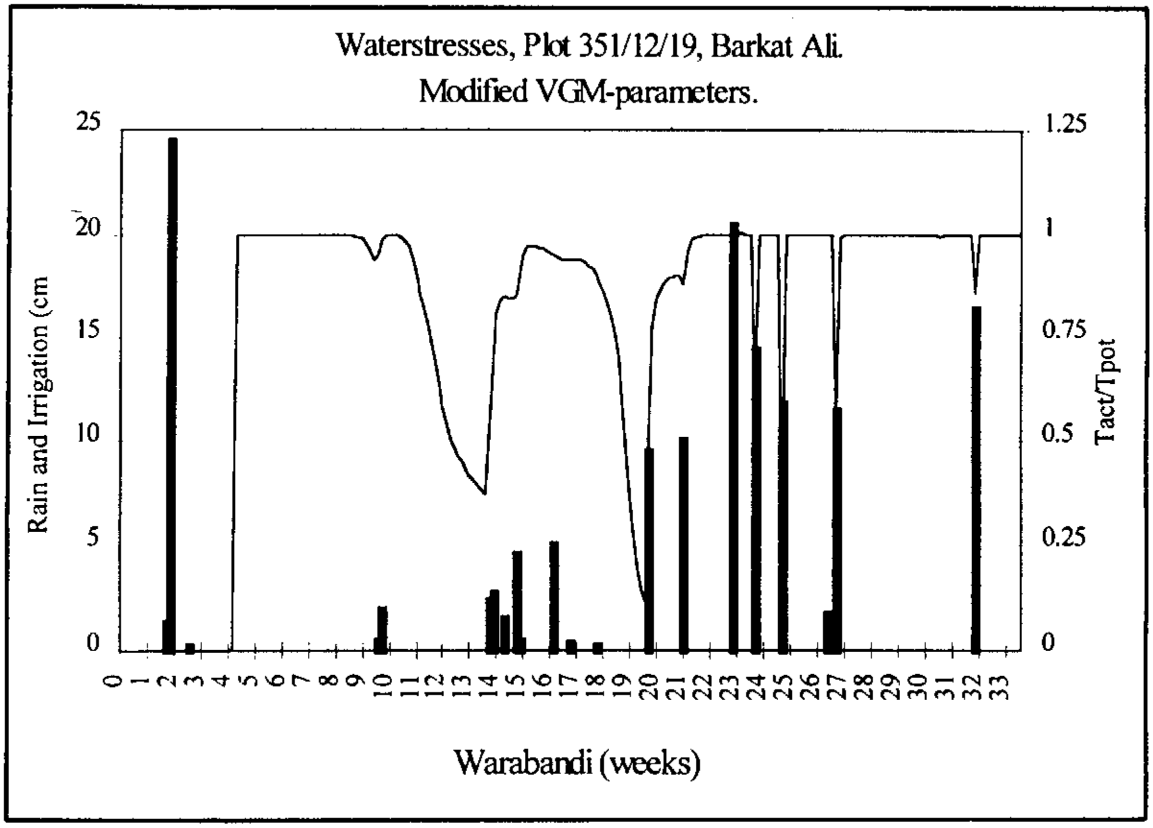

Figure 2.1.b. Waterstresses with modified VGM-parameters.

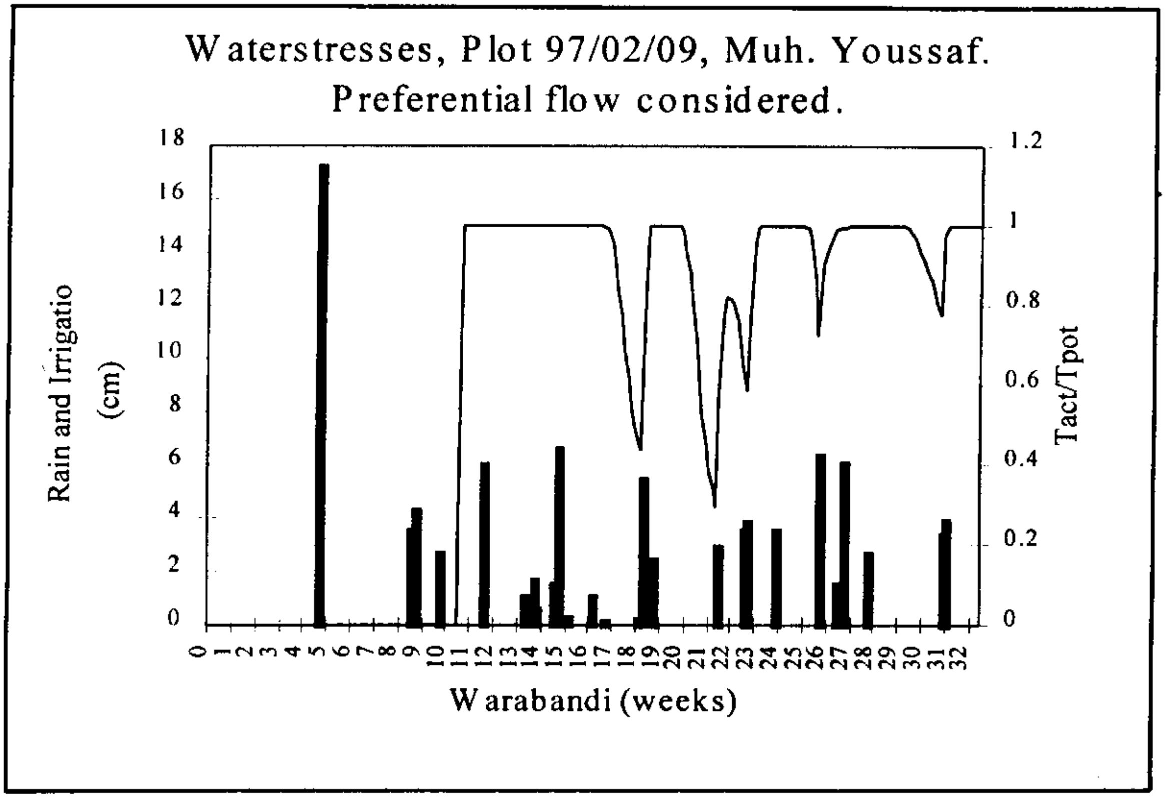

Figure 2.2.a. ***Waterstresses with preferential flow.***

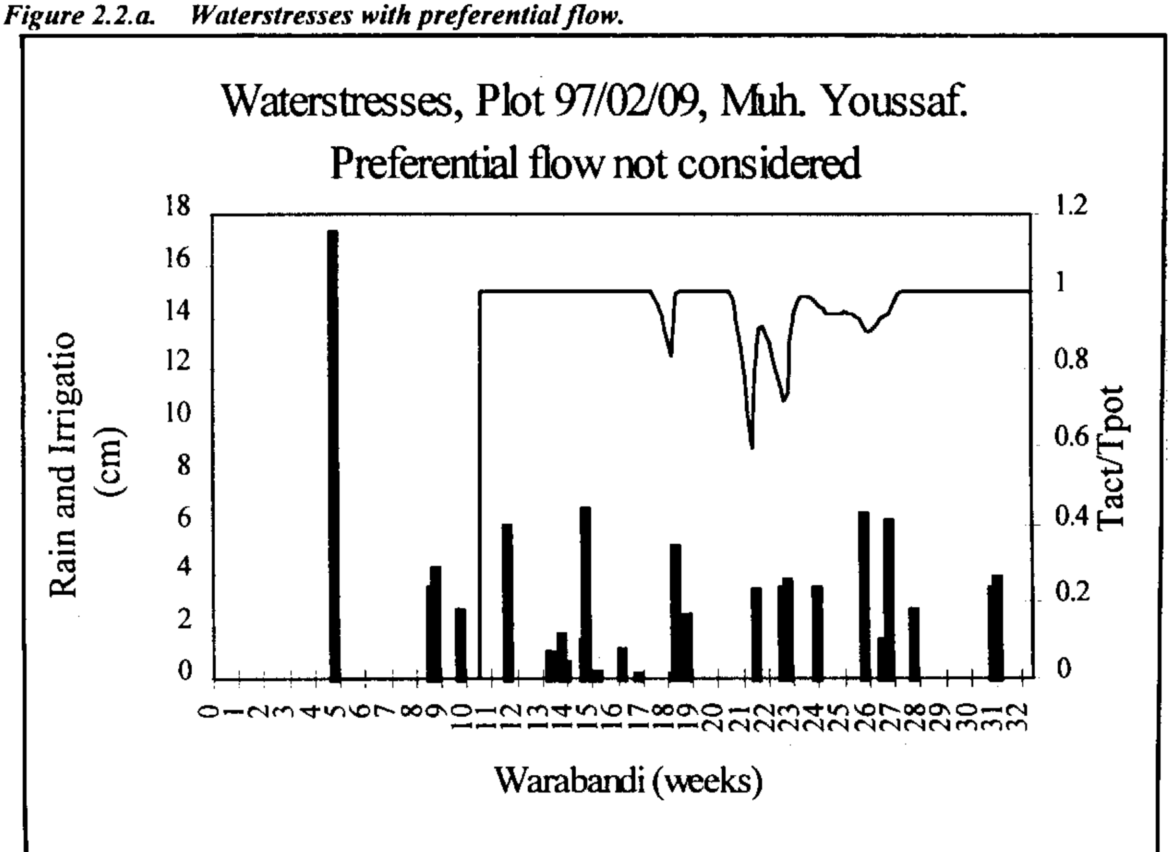

Figure 2.2.b. ***Waterstresses without preferential flow.***

To every farmer it was presented which activities he carried out at the fields and why he carried them out that way. This was done by abstracting an average sequence for each farm and also by making an assessment of the deviations for each field, due to specific events. This average sequence was visualised on a big board, with both the Western and the local, so called Desi calendar on it. On this board cards were placed which represented the farmers activities. Blue for irrigations, yellow for labour activities, purple for inputs used like spray and fertilisers. The activity was represented in a clear and schematic manner and the names were written down in Urdu. Also cards were drawn to represent the different crop stages. The farmer, by using this cards if he wanted to, could point out whether the perception of his practices was according to reality. In some cases though it was difficult to make use of the cards, because the restitution was done outside, where it was windy, or inside were a fan would blow because of the heat. In that case the presentation of the average sequence was done completely orally, only the calendar was used to indicate the timing. Also this was satisfactory.
The second part of the restitution was to discuss alternative management during the cotton season. For this stage of the restitution some alternatives were formulated which were achievable within his farming system for each farmer. For instance, no 3 bags of fertiliser were recommended to a farmer with little financial resources. The alternatives were presented as suggestions to the farmer, to make clear that it might be improvements, but that it would need some try-out to see whether the crop would perform better.

2.5. Relating the technical sequences to the farm typology.

Each technical sequence of a farmer is related to the farm characteristics and therefore to the typology. The most simple example for this is the increasing amount of fertilisers by a higher cash availability and the better water availability due to the possession of a tubewell.
This relation was established in three ways:

- A description of each farmer to evaluate the reasons for his practices and the impact of his practices on the yield was analysed. This description can be found in Annex 7 to 20.
- The creation of a number of average sequences each related to a certain strategy. With the information obtained from the write out it could be observed that for a certain reason a farmer would pick a sequence or a combination of sequences.
- Relating the cotton cultivation strategy to the water allocation within the farm. The irrigatio practices at the cotton fields were explained by analysing the water allocation to other crops an fields. See Chapter 2.7.

2.6. Establishing a production function by statistical analysis.

After the farmers description and the information obtained through the agronomic analysis it was clear which factors were influencing the cotton production. All this factors were quantified in various ways, i.e. labour use per growing stage in hours/ha or in number. A total number of 175 variables per sample field was established to perform regressions on.
The program used for the analysis was SPSS, a statistical software package. At first only linear function forms were tried, but when it occurred that due to colliniearities (dependency between variables) the significance was low also quadratic function forms were used. Indications for this had already been supplied by literature in case of the waterstress-yield relation.
Problem this year was that virus attack was high. The virus attack itself was monitored in September of that year, but the classification used did give little impression of the severeness of the attack itself. Virus attack is not only dependant on spray use and timing of the first spray after the beginning of the attack, but also dependant on variety, spray use in the neighbourhood, fluctuations in micro-climate due to vegetation. All variables which can not be modelled with the available data.

2.7. Relating the intra-farm water allocation principles to the cotton cultivation strategies.

The knowledge concerning intra-farm water allocation was obtained during the research regarding cotton cultivation.
An inventory of factors determining the intra-farm water allocation was done. This inventory can be found in Annex 5. On the basis of this inventory and the available data a methodology was developed.
First step was to create a *cropping pattern* for Kharif '95 for each farm. Next for each field it was determined how much water was allocated during the Kharif. Afterwards the *water allocation to each crop within the farm* could be calculated. Here already priorities for crops, priorities at a certain stage, priorities in quantities of canal or tubewell water, could be distinguished. Next step was to analyse *the impact of this water allocation at the farm level on the plots itself.* In order to analyse this for each field the ratio of the actual evapotranspiration over the potential evapotranspiration, i.e. *the waterstress*, was calculated by using CROPWAT (Smith (FAO), 1992).
Due to the time constraint in this report only the analysis of 7 farmers is done. Their analysis is integrated within the relation cotton strategies-average sequences discussed in Chapter 5.

<u>CROPWAT-SWAP93 Comparison</u>
Without considering the structure of the two models, some conclusions can be done concerning the differences in output. In general the output of CROPWAT and SWAP93 are quite equal in the timing and duration of the waterstresses that occur. Were SWAP93 gives the T_{act}/T_{pot} relation indicator for the waterstress, CROPWAT supplies a ET_{act}/ET_{pot} relation, but still the value of the waterstress itself does not change considerable.
Even in the case of Muh. Irshad and Shakar Ali, where SWAP93 takes into account the ground water tables and the capillary rise, the differences are small.
To illustrate this, output graphs of both SWAP93 and CROPWAT for 2 plots of Muh. Irshad and Muh. Yaqoob are displayed in Figure 2.3.a. and b. and Figure 2.4.a. and b.

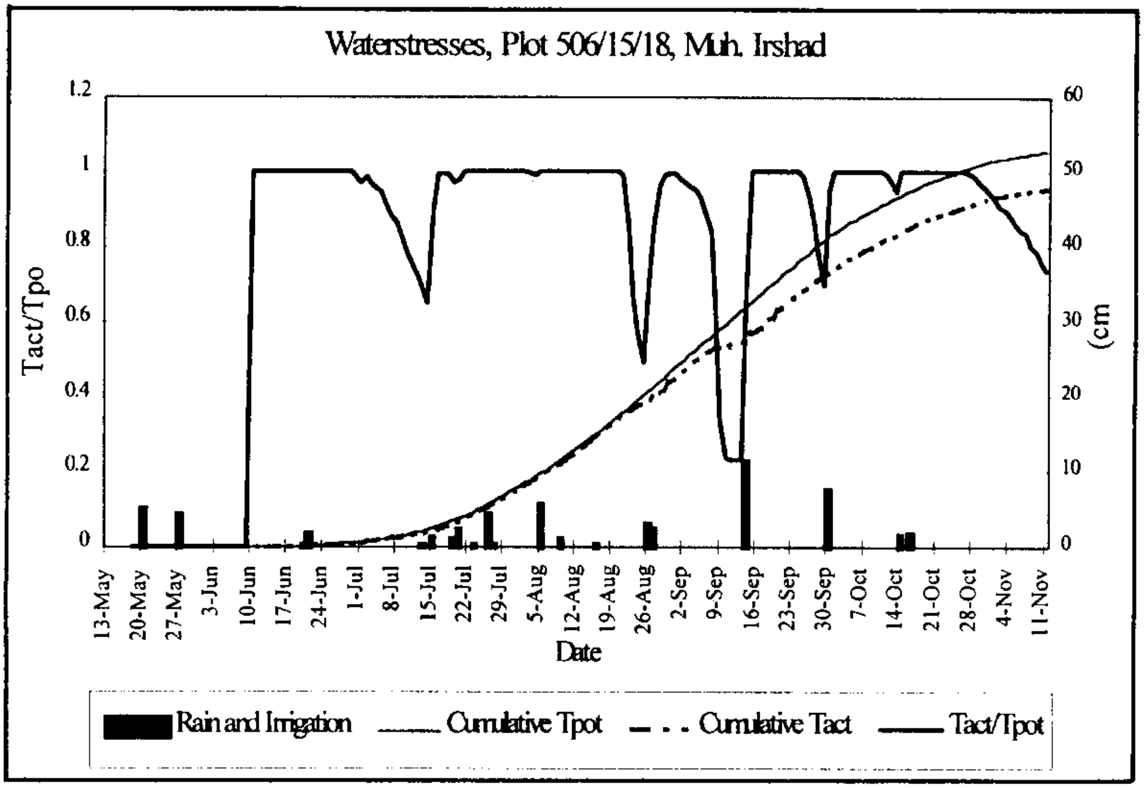

Figure 2.3.a. Waterstresses at a plot with high groundwater table according to SWAP93.

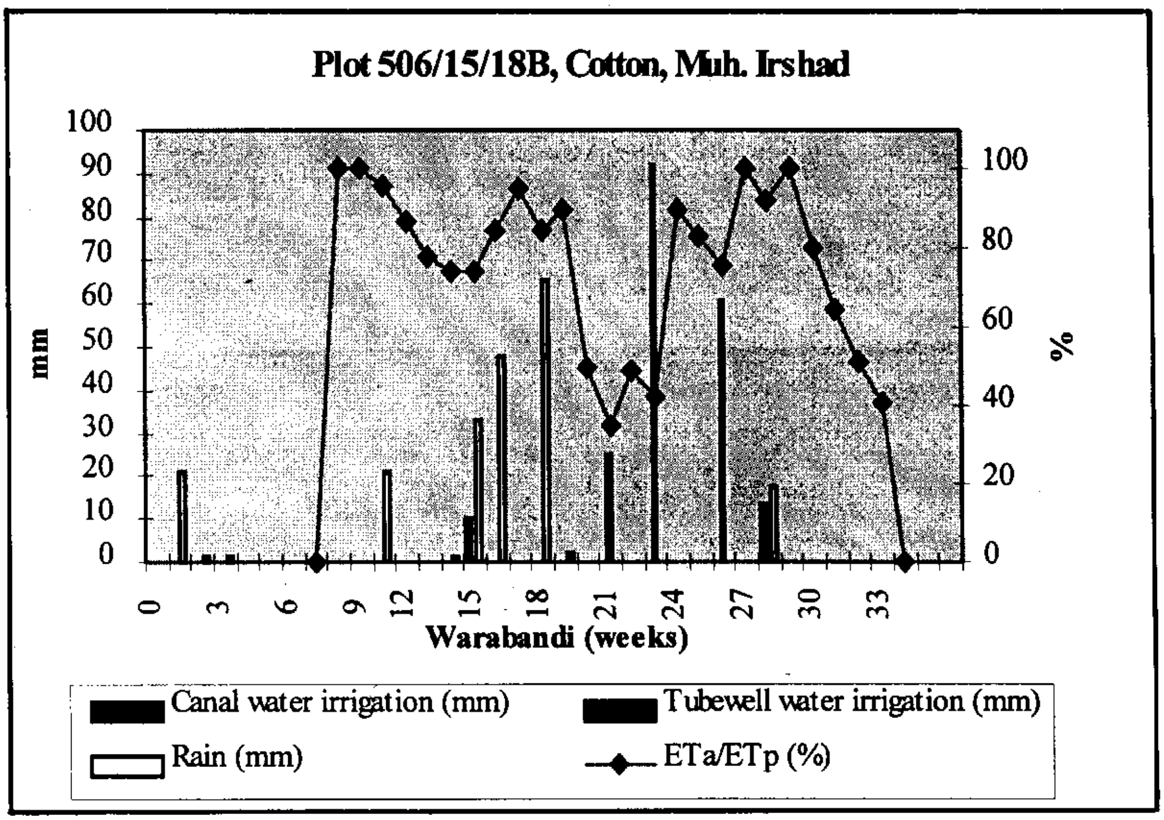

Figure 2.3.b. Waterstresses at a plot with high groundwater table according to CROPWAT.

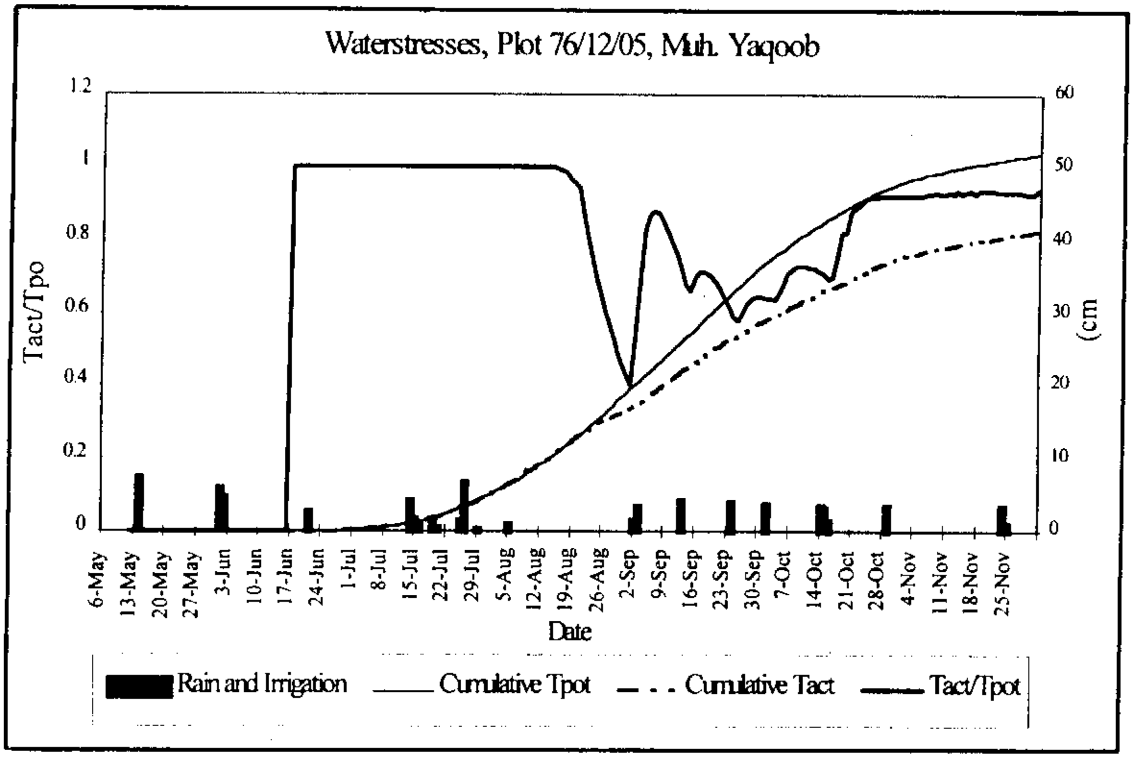

Figure 2.4.a. Waterstresses at a plot according to SWAP93.

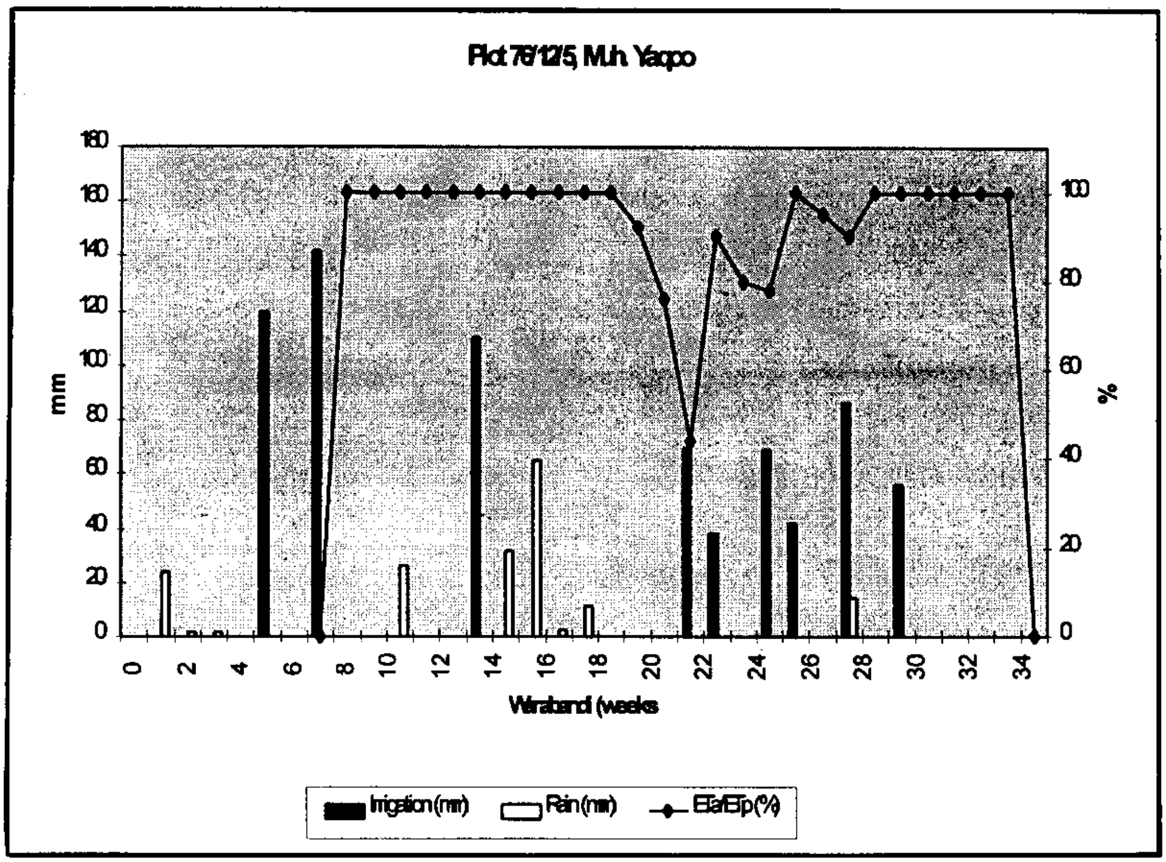

Figure 2.4.b. Waterstresses at a plot according to CROPWAT.

CHAPTER 3 ANALYSES OF COTTON PRACTICES

3.1. Growth and development of the cotton plant

General

Most of the cotton varieties (*Gossypium Hirsutum* L., English: *American upland cotton*) used in the world have an indeterminate growing cycle, so over a relative long period (130-180 days) vegetative growth and reproductive growth are combined. According to Grimes and El-Zik the cotton plant is therefore more complex than any other major field crop. An exception on this is a determinate variety that is commonly used in Pakistan, CM-240 (pers. comm. A.A.R.I.F.).
In the development of cotton the stages that can be distinguished are:

- Germination of the seeds.
- Emergence of the seedlings.
- The squaring, i.e. the formation of flower buds (in which a the major part of the vegetative growth takes place).
- The early flowering.
- The peak flowering.
- The boll formation.
- The boll opening.

The length of each stage is both variety and climate dependent. The most common way to express the duration of each stage is in the amount of degree days, i.e. the summation of degrees centigrade above the developmental threshold value of 15.5 ^{0}C for each day of the stage. In the USA the total length of the growing cycle could differ 55 days due to differences in degree days for different cotton growing regions (El-Zik and Frisbie, 1985).

For the Hasilpur region no data were available to assess the development of the cotton plant according to this method and therefore the average calendar for cotton development for the Punjab was used. For the Punjab, the phenology of an indeterminate variety, sown in the beginning of June, is shown in Table 3.1.

- Germination and emergence of seedlings

The seeds of the cotton consist of two cotyledons (seed leaves). Other parts are the epicotyl, the hypocotyl and the radicle. All the necessary nutrients for germination and emergence are stored in the seed leaves itself. Necessary for a good germination is a moist soil with enough available oxygen and a well prepared seedbed (pers. comm. A.A.R.I.F.). According to Grimes and El-Zik soil temperature should be higher than 17.8 ^{0}C. This aspects will be discussed in more detail in Chapter 3.2.1.
At the emergence first the roots will develop before the leaf expansion starts.

- Vegetative growth

Vegetative growth occurs mainly during the squaring and the early flowering and to a lesser extent the peak flowering.
At the vegetative growth cotton is producing a series of nodes and internodes which create the main stem. The number and length of the nodes are dependent of the variety which is used and the growing conditions. According to El-Zik and Frisbie, 1985, the first fruiting branch normally appears at the

5th to 6th node, for early flowering cultivars the first squares will appear at the 4th or 5th node and for long season cultivars this can be on the 9th node. The higher the first fruiting branch develops, the longer it will take for the bolls to maturate.

Table 3.1. Phenology of CIM-109, sowing date June 7.

Growing stage	Length	Days after sowing	Corresponding dates
Emergence	7 days	0 - 7	June 7 - June 14
Emergence to squaring	20 days	7 - 27	June 14 - July 2
Squaring	21 days	27 - 48	July 2 - July 23
Early flowering	28 days	48 - 76	July 23 - August 20
Peak flowering	25 days	76 - 101	August 20 - September 14
Bolls maturation	40 days	101 - 141	September 14 - October 24
Opening of bolls	39 days	141 - 180	October 24 - December 2
Total growing season	**180**		

Source: C.C.R.I.M., A.A.R.I.F.

- Root development

Cotton has a primary taproot with many laterals. According to Bassett et al., 1970 the root length density shows a sigmoidal curve due to exponential growth in the first part of the season. In that period the taproot can grow with a speed of 2.5 cm/day for a period of several weeks after planting. About 50% of the roots is in the top 60 cm of the soil. According to the Smith, 1992, an average rooting depth of 140 cm is established at the onset of the flowering, so between 70-80 days after sowing.

- Fruit formation

The indeterminate cotton varieties produce squares (flower buds), flowers and bolls over a period of 80 to 90 days. The development of the flowers is clearly a function of the vegetative growth, which determines the number of fruiting branches. A decline in squaring can be due to different factors, like excessive or too little soil moisture, heat or cold, cloudy weather or damage from insects (Guinn, 1982).

- Bolls maturation

According to El-Zik et al., conversion of flowers into bolls is more effective in the first stage after flowering. In total 80% of the bolls are set in the first 3 to 6 weeks of flowering. Late in the fruiting season the cotton starts to cut out, so no new nodes and squares are formed. A premature cut out might be caused by moisture stress and extreme temperatures, and so yield and fibre quality might be reduced. The cotton fibre itself is an extension of the epidermal cells of the seed. The quality of the fibre is largely determined by the variety, moisture stress and pests.

Cotton growth in the Hasilpur region

In the region of Hasilpur several varieties are being used. The main diversion that can be made is between the *Gossypium Hirsutum* L. and the *Gossypium Arboreum* L. (English: *Tree cotton*). The later is also called Desi-cotton, i.e. local cotton, and has as main characteristics that it has a short lint, is adapted to the local circumstances and has a longer growing season, a lower water and fertiliser demand, a lower yield and a higher yield security and also resistance against viruses is higher. More nodes are formed during the vegetative growth and therefore it is a high plant. Except from differences in requirements, the main differences between the *Gossypium Hirsutum* L. and the *Gossypium Arboreum* L. is the length of the growing season. The *Arboreum* is sown one month before the *Hirsutum* and harvested at the same time.
According to A.A.R.I.F. the *Gossypium Hirsutum* L., to which all the commercial varieties belong, can be divided into two types:

1. The indeterminate varieties, for instance CM-109, NIAB-78, MNH-193.
2. The determinate varieties, i.e. CM-240.

The main difference between the indeterminate and determinate varieties is the length of the emergence and the vegetative growth period. The period from sowing to peak flowering is 10 days shorter in case of a determinate variety.
From all the sample fields 60% is being cultivated under CM-240, 30% under the indeterminate varieties (BH-36, S-14, CM-109, NIAB-78, MNH-193) and 10% under Desi cotton. CM-240 is selected in most cases because it is widely available, its' potential results are known and the yield is high. It is also reported to be the most water and inputs consuming variety. For this variety early inputs, fertiliser at sowing, irrigation short after sowing, would give the best results. Most of the farmers are not aware of this characteristics and do not apply fertiliser at sowing and do also not apply an early irrigation or early fertiliser, as can be observed from the technical sequences.
The indeterminate varieties are used since they use less water than CM-240 and also inputs can be less. About the yield performance little consensus exists, where one farmer cheers their good yield performance, the other is depressed by it. Especially S-14 is a variety with extreme yield performance. Once it is kept free from deficiencies and diseases the yields are very high, but slight deficiencies can depress yields severely. Farmers who were using the indeterminate varieties, which need late irrigation, were complaining about the effect of the early rains. This early rains caused the crop to be bushy, but later on flowers and bolls were small. Most of the time farmers are not aware of the characteristics of the variety they are sowing. They mainly rely on the experience of last year and on the experience of other farmers when they decide which variety to use.
Desi cotton is cultivated mainly for household use, since the short lint is not suited for cloth production. Its' lint is used for filling pillows and blankets. One farmer, Muh. Yaqoob reported this year that he sold the Desi at the market for a slightly lower price than the normal cotton.

3.2. Soils in the Hasilpur Region

Over the sample watercourses variability in soils is large. Five major soil series can be distinguished in the region, according to their textural groups (Soil Survey of Pakistan, 1995). This is displayed in table 3.2.
In general it can be stated that the agricultural potential is increasing with decreasing salt contents. On the other hand the impact of sodicity and salinity is bigger and soils with higher clay contents.
From the sample fields 15 fields can be classified in coarse textured group, 29 fields can be classified in the moderately textured groups, and 14 fields can be classified in the medium textured groups.

Also a local classification exist, displayed in table 3.3.. For the sample fields five textural classes can be distinguished. Also soils were mentioned with high contents of "bhal", fertile canal water sediment.
For quite some fields classification of the SSoP was not according to the local classification. Fields that for instance were judged as plots with a low agricultural potential, were considered as very good soils by the farmers.

Table 3.2. Soils in the Hasilpur Region according to the SSoP classification.

Textural Group	Range	Soil Serie
Coarse	Fine Sand to Loamy Fine Sand	Jhang, Sodhra
Moderately Coarse	Loamy Sand to Fine Sandy Loam	Rasulpur
Medium	Very Fine Sandy Loam to Silt Loam	Sultanpur, Nabipur, Harunabad, Awagat, Bagh, Jakkar (sal./sod.)
Moderately fine	Clay Loam to Sandy Clay Loam	Miani, Balighe, Adilpur (sal./sod.)
Fine	Sandy Clay to Clay	Pacca, Matli, Satgara (sal./sod.)

Source: Soil Survey of Pakistan.

Table 3.3. Soil in the Hasilpur region according to the local classification.

Classification	Textural Group	Number of sample fields
Bareek Rate	Sandy (formerly dunes)	10
Ratly	Loamy Sand	18
Halka Mera	Fine Sandy Loam	5
Bhari Mera	Silt Loam/Loam	13
Packy	Clay Loam	11
High bhal content		4

Source: Master Aslam.

3.3. Effects of cultural practices

3.3.1. Seedbed preparation

General

The germination stage and therefore the seedbed preparation is very essential, since Krieg and Bartee, 1975, report that the final yield and lint quality are highly affected by the seedling establishment.
A good germination is achieved given the following preconditions:

1. A moist soil with enough available oxygen.
2. A well prepared seedbed.
3. Soil temperature higher than 17.8 ^{0}C.
4. Good seeds.
5. A low salinity of the top soil.

6. Sowing depth 2", row spacing 75 cm.

ad 1. A moist soil is according to the local recommendations a soil which is at "wattar-condition", i.e. a soil moisture content, volume-based, of the top layer of ± 10-15% (pers. comm. A.A.R.I.F.). Soil moisture contents should not be too high in order to allow soil tillage activities.
At sowing it is best to fill the expected rootzone with water until field capacity, as a reserve for later growing stages. At later stages the evapotranspiration will be that high that water applied to the field will not reach all the way to the deepest roots. At sowing it is important that the contact area between the moist soil and the cotton seed is as large as possible.

ad 2. A well prepared seedbed is a soil which is well crumbled over the top 20 cm, with a good distribution of macro- and micro pores in order to ensure aeration and rootability. The seedbed should be horizontal to achieve good irrigation uniformity. This is done by ploughing, planking and levelling. Factors which can influence the quality of the seedbed are:

1. Organic matter content of the soil. Low organic matter contents lead to compaction of the soil and a decrease of the workability of the soil.
2. Sodication. Due to sodication the hydraulic conductivity will decrease and swell and shrink properties will increase. This will affect the pore distribution in the soil. This effect will especially occur on loamy soils.

ad 4. In order to guaranty good seeds the government is having a certification system. This government- certified seeds are normally the best. If the seeds are not cleaned, i.e. delinted, this should be done with sulphuric acid. Cleaned seeds germinate better. Not only does the seed have a larger contact area with the moist soil, but also the acid itself stimulates germination. It is also recommended to soak the seeds before sowing.

ad 5. Germination is the most sensitive period for salinity. This will be discussed in more detail in chapter 3.4. Since the EC of the irrigation water is dominant for the salinity status of the top soil, the first irrigation should be done with low EC water, like canal water.

ad 6. Since cotton is a dicotyl it has to push-up its' two rudimentary seed leaves. Therefore the seed should not be sown too low to avoid soil from tumbling on it. Row spacing of 75 cm is not directly needed for a good germination, but it is necessary to ensure enough space for the plants in a later growing stage. (Note: The correct term for the way of sowing as it is recommended is *planting*, since the seeds are distributed in a regular pattern and not broadcasted.)

<u>Seedbed preparation in the Hasilpur region</u>

* Germination-yield relation

According to Malik et al., 1996 , the total leaf area index of the plants on the field is a good indicator of the germination of the seed. Therefore also the soil cover and the density of the plants on the field is a good indicator. For the sample fields a visual estimation of the density of the soil cover was done in September by two field assistants. The density as it was observed was not clearly defined, but it could be observed that it was correlated to the yield as can be seen in Figure 3.1.

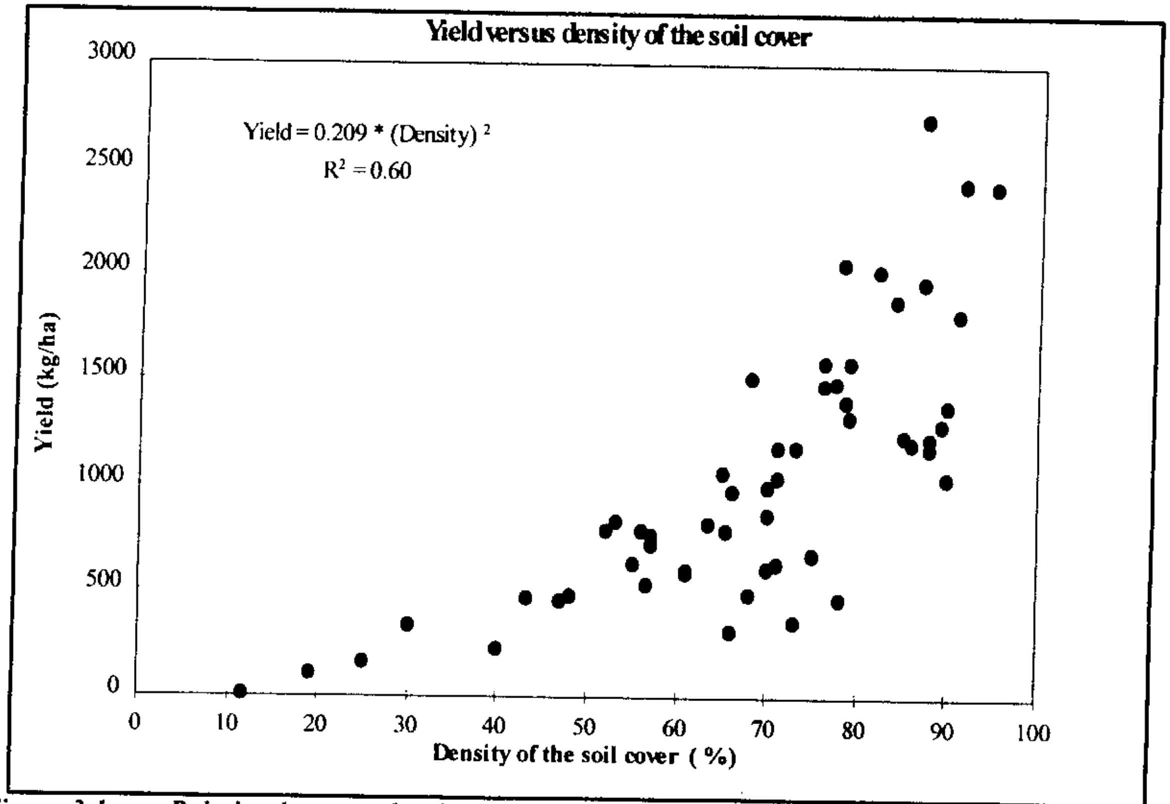

Figure 3.1. Relation between density of the soil cover and final yield.

From Figure 3.1. it can be observed that high yields only can be achieved in case of a good germination. But also yield variability due to other factors than the germination is increasing with higher densities. So once a crop establishment is good bad yields still can be achieved due to bad management or accidents.

* Sequence

The common sequence in order to establish a good seedbed for cotton is:

Wheat harvest
Kacchi Rauni
Two ploughings
Pakki Rauni (pre-soaking irrigation)
Levelling
Two ploughings
Planking
Sowing

- Wheat harvest

Wheat is normally harvested at the end of April. The processing of the wheat, cleaning, storing, selling, takes about 20 days.

- Ploughings

On average four *ploughings* are done before sowing the cotton, most of the time by cultivator, but also chisel plough and rotavator are used. The ploughing depth of a cultivator and a rotavator is around 6", for a chisel plough the depth is 9". The amount of ploughings is less than at the beginning of the Rabi, since the wheat is not rooting deep and therefore the stobbles are removed easily. Also a thresher is used in some cases to remove the stobbles.
The amount of ploughings ranges from about two in sandy fields, where the soil does not need to be crumbled that much[11], to 5 or 6 at more loamy fields. One farmer even performs 12 ploughings between harvesting sugarcane and sowing the cotton. On some loamy fields at Azim 111-L also rotavator is used, which effect is said to be the same as 6 times ploughing. The ploughings are done before sowing the cotton. The ploughing depth that is mostly used by farmers is around 6"

- Rauni

According to the recommendations, the *rauni* has to fill the soil till the maximum rootzone of the cotton plant, approximately 1.4 meters deep. In order to infiltrate that much water it is best to give two raunis, a kacchi rauni and a pakki rauni.
For most of the farmers this is not the most important effect of the rauni. It is considered more important to soften the soil for the ploughings and to remove the weeds by improving germination. Therefore usually only one rauni is given. The farmers try to apply the rauni with canal water or low EC tubewell water. Therefore in the period of sowing a shortage of canal water exists at the tail end of the distributaries and the watercourses, since illegal extraction increases.

- Levelling

The main function of *levelling* is to level the plot in order to achieve a good irrigation uniformity and so a better irrigation efficiency. Another function is, as is planking, to compact the top soil and therefore preserve moisture.
Levelling is performed at 67% of the fields. The farmers who do not level say it was not necessary to do so for this particular fields and the farmers who do so consider it most of the time as a normal practice that has to be done on every field.

- Planking

After ploughing the soil is very rough and the evaporating area per square meter is high. So the function of *planking* is to crumble the last clods and to "press the moisture in the soil" by reducing the evaporating area of the topsoil. By this means the "wattar-condition" of the soil can be achieved. It is done by pulling a heavy piece of wood, sometimes with a person on top of it, by tractor or oxen over the field.

- Sowing

The most common method is to sow with a tractor and drill. In this way a regular cropping pattern can be achieved, which will make future practices more easy.
Some farmers practice sowing with oxen and a plough on which a funnel is constructed, through which they drop the seeds. This method is as good as sowing with a tractor, but is more time consuming.
Sowing is on average done in the second week of June, ranging from the first week of May for Desi-cotton and the beginning of July for some fields at Fordwah 130-R. This is 3 weeks later than the

---

11 *According to the Extension Service Hasilpur more than two ploughings on a sandy soil will cause a deterioration of soil fertility by moving the topsoil to the subsoil. This is denied by Khan (pers. comm.) of A.A.R.I.F.*

recommended date of the extension service, mid-May. Farmers are aware that sowing should be done earlier, but they experience the following constraints:

Labour constraint.
Most of the farmers wait with the seedbed preparation until all the wheat, is processed, stored or sold. Labour constraint in the region at this time is high.

Lack of canal water
For the farmers at the tail-end of the system, Fordwah 130-R, were soils are sodic and canal water availability is poor, the seedbed preparation and the sowing is delayed by the complete absence of canal water at this time. This canal water is necessary to remove the salts from the top soil.
Sowing here was mostly done at end June. At a certain moment some farmers had to decide to prepare the seedbed with tubewell water, so the germination of this cotton was effected. Farmers at Azim 111-L, the other tail-end canal, had to irrigate with tubewell water any way, so there sowing dates were normal. Germination was not effected severely, since tubewell water quality is relatively good (Electrical Conductivity (EC) < 0.75 dS/m).

Bad germination
On some fields germination was not good and so it was necessary to resow. This gives a delay in sowing of about a week. This bad germination can mainly be due to three reasons:
a. Low organic matter content, so hard soils. This is especially the case with loamy soils.
b. Sodicity/salinity, so hard soils and toxic effects on the seeds
c. Bad seed quality

Lack of tractors
Farmers who are convinced of the need to perform the seedbed preparation with a tractor, but do not own a tractor themselves see themselves confronted with a lack of tractors to rent at this time, since the demand is high.

Early rains
If sowing was already delayed, farmers saw their crop destroyed by early rains. At June 21 a big shower appeared (22 mm), which caused quite some damage to the seedlings. This effect especially occurred at fields were the sowing was done late already, since the plants were more weak there. On this fields sowing had to be redone.
Also early rains lead to crust formation on loamy soils. By this aeration and the permeability of the top layer for the seedlings decrease.

- Plant spacing

Common practice as it is recommended by the Pakistani research institutes is to sow the plants in rows, which are 75 cm apart. Spacing in between plants in the rows should be 30 - 35 cm. According to Cherry and Leffler plant growth is affected by the plant density per unit area. Young seedlings growing in thick stands tend to grow taller than those in thinner stands. Light penetration into the canopy in thinner stands may cause the plants to effectively initiate reproductive development sooner than those in thicker stands. Walhood and Johnson (1976) achieved a significant yield increase by altering the intra- and inter-row spacing.

- Cottonseeds

Most of the cotton seeds are purchase from the market. For the farmers it is quite a hassle to decide which seeds to purchase and where to buy them. There were quite a few cases (3 of 14) were farmers had been cheated by the shopkeeper and did not get the variety they would like to have.

All the research institutes recommended government- certified seeds to be purchased, but according to the Hasilpur Extension Service and the farmers, this seeds were not available in the region.
It was not recorded whether the farmers cleaned the seeds with sulphuric acid and pre-soaked them before sowing. When asked to several sample farmers they reported that they had done it and that it was a common practice for the vast majority of the farmers they knew.

3.3.2. Soil tillage at vegetative growth

General

- Making furrows

According to Master Aslam and the Extension Service Hasilpur the first thing to do after the germination is to make furrows and ridges. This is a way of increasing the irrigation efficiency, since the wetted area of the field is being reduced and the advance of the water front will be faster. This will lead to a more uniform infiltration. The ridges also support the cotton plant. Furrows are made 2 to 3 days after sowing, sometimes later when plants are already high. The practice is more needed on sandy soils where a lower supporting capacity and a higher infiltration rate cause a slower advance of the water front over the field. A disadvantage of it is that it makes ploughing more difficult. The slope of the furrow will be on top of the seed. Due to irrigation the ridge will move towards the stem of the cotton, were soil particles are being held together. Another advantage of furrows is that salts will deposit on top of the furrow and not around the seedling.

- Thinning

The thinning has to be done as soon as the plants are 6" high, 20 to 25 days after sowing. Distance between plants is in general 12" to 15" and preferably the bad plants have to be removed. If thinning is not done the plants will compete for nutrients, water and sunlight, which will at the end lead to a yield decrease.

- Hoeing

After thinning two intercultural (between the plant rows) hoeings, at 3" to 4" depth with a light cultivator, will be done, mostly with tractor. The first one has to be given 3 to 4 weeks after sowing, the second one is given 10 to 15 days after the first one. The main function of this is to preserve the moisture in the soil. The topsoil will loose more water, but the capillary rise of the water is being stopped, by disconnecting the micro- and macropores. Also weeds are being removed partly and the aeration of the soil is increased. In addition to this a hand weeding has to be done, but preferably the use of herbicide is needed. Instead of applying this to the whole field it is best to spray it between the plants and have the weeds between the rows removed by the hoeing. At this way one-fourth of the quantity is needed. The amount of hoeing depends a little bit on the cotton being of a sympodial or monopodial[12] variety. The monopodials will "grab" each other and therefore be more tight. The sympodials leave more space to grow to weeds.
Due to its' moisture preserving effect the main purpose of hoeing is to delay the first irrigation as long as possible. A quick irrigation will give cotton like trees. At this way a lot of inputs are being used for the vegetative growth, where they should be used for the reproductive growth.

12 *In case the elongation of the plant is achieved by the growth of the main stem, one speaks about monopodial branching. In case the elongation of the plant is achieved by the growth of the branches, one speaks about sympodial branching.*

So irrigation is delayed up to 40 to 50 days for the non-determinate varieties and 30 to 35 days for the determinate varieties by means of hoeing. Also hoeing before irrigation or a rain increases the speed of infiltration and assures that more water is used for cotton itself and not for weeds. Therefore a sequence of hoeing and then irrigating is profitable.
Hoeing should be done in total 2 or 3 times until flowering and stop afterwards, to make sure the plants do not break.

- Long-term tractor use

According to the extension service a ripping/deep cultivation should be performed once in 8 years on loamy soils and once in 12 years on sandy soils when a tractor is used. Due to the weight of the machinery a hard pan can be formed, i.e. a compaction of the soil at a depth of ±50 cm.
After this ripping the soil should be left fallow for one cropping season, to restore its' structure and the organic matter content. Therefore it is an expensive investment to be made, due to the fuel costs and the fact that the field can not be cultivated for one season.

Soil tillage in the Hasilpur region

The flowering is starting from mid-August till the beginning of September. Before this period there is one big shower, mentioned before, on June 21 and a series of showers from mid-July to the beginning of August. This rains were coming earlier than expected and most of the farmers said that it had a negative impact on crop development. Water was ponding on the fields, so aeration decreased, and the impact of the raindrops itself was said to damage the young crop.
Before this rain most farmers managed to perform one hoeing by hand, i.e. using the kisa (shovel). Labour requirement is around 20 hours/killa. This is a major constraint for farmers and therefore more hoeing, 1.3 on average, by tractor or oxen (2 farmers) is done. The hoer behind the tractor scrapes the soil, thus removing the weeds and breaking the topsoil. This takes one hour. If it is done with oxen a normal plough is used, and it will take about four hours/killa.
Thinning is only done on very few fields (4 in total). Especially when sowing was late it was, according to the farmers, not necessary to perform this practice, since density was already low. Information about plant spacing and plant populations were not available for the sample fields.
The difference in definitions used by different field assistants did not allow to judge whether furrows have been made on all the fields. The making of furrows might be specified by using this name for the activity, but it appeared that the activity itself could also be captured by the term hoeing or ploughing. Probably the making of furrows is mostly combined with this activities. At all the fields seen personally, it appeared that it was a common practice for all the farmers in the region.
Furrows are also used to create boundaries, in order to irrigate the field in small parts. By irrigating a small part at once the uniformity of the application increases, since the time to cover the whole plot surface with water decreases. Common practice on sandy soils, with higher infiltration rates and therefore more hazard for a low irrigation uniformity, was to divide one killa in six plots. On loamy soils one killa was divided in four plots.
After the rains 50% of the fields were hoed by hand again and all the fields were at least once hoed by tractor or oxen. This activities started as soon as the rains stopped.
At this moment most farmers prefer to go through the field with a tractor since flowers are appearing. The tractor moves over the cotton and does not disturb the crop and it takes only one hour/killa. Hoeing by hand has the effect that people walk through the fields for one day, have to loosen the soil by hand and in that way give more damage to the crop.
On average 28 hours per killa hand labour and 5 hours per killa machinery is used. It ranges from 0.0 hours per killa for Qazi Muh. Ali to 88 hours per killa for one field of Barkat Ali.

Only one farmer, Haji Elahi Baksh, is performing a ripping/deep cultivation once in a while. After that he does not leave the land fallow. He is aware of the necessity, but the yield from this fields is needed. Three other farmers with a long-term tractor use, Qazi Muh. Ali, Muh. Yaqoob and Muh. Islam do not perform this practice. Especially Qazi Ali, with the most loamy soils, is assumed to have a hard-pan formation.

3.3.3. Fertiliser application

General

The fertilisers that a cotton plant needs can be distinguished in 3 groups:
1. the nitrogen fertilisers (N-group).
2. the phosphate fertilisers (P-group).
3. the potassium fertilisers (K-group).

The main characteristics of a fertiliser are the content, the pH and the purity. For common fertilisers used in Pakistan this characteristics are mentioned in table 3.4.
It is reported by Berger that cotton yielding 560 kg lint /ha extracts about 40 kg N/ha, 3.5 kg P/ha and 7.1 kg/K, 4.2 kg Mg/ha and 2.9 kg of Ca.
The nutrient requirements can be divided in two groups, according to Joham, 1986. The first group is having an important role in the vegetative growth and consists of N, S, Mo and Mn. Their impact on the fruiting efficiency, i.e. the ratio dry weight of bolls/dry weight of stems is little. The second group are P, K, Ca, Mg, B and probably Zn. Zn is reported to have its effect on the partition of vegetative and flowering period (Joham and Rowe, 1975), and therefore has a profound effect on fruiting.

- Effect of pH

Fertilisers with a low pH should be applied. A high pH reduces the Cation Exchange Capacity and therefore has a negative impact on the ability of the soil to supply nutrients and on the structural stability of the soil. In general every fertiliser with a pH lower than 7 can be considered good (pers. comm. S.F.I.L.).

Table 3.4. Characteristics of fertilisers.

Name	N (%)	P (%)	S (%)	K (%)	Ca (%)	pH	Purity
N-group							
Urea	46	-	-	-	-	8	0
Calcium Ammonium Nitrate	26	-	-	2	8	7.0	Zn(0.7%) Mg(0.05%), Cu, Bo
Ammonium Sulphate	21	-	24	-	-	4.0	unknown
P-group							
Single Superphosphate	-	20	12	0.2	20	2.0	Mg(0.2%),Trace elem.
Nitrophos	23	23	2	-	9	3.5	Mg(0.1%),Trace elem.
Triple Superphosphate	-	46	1.5	-	14	4.0	unknown
Diammonium phosphate	18	46	-	-	-	8.0	0
K-group							
Sulphate of potassium	-	-	18	50	1	8.0	Trace elements
Others							
Zinc Sulphate	-	-	13	-	-	?	35% Zn

Source: Soil Fertility Institute Lahore.

The pH is a function of the cation-anion complex. K-cations give a decrease in pH were Na cations increase the pH. Ca-cations have the biggest decreasing effect on pH. Carbonate-anions increase the pH, sulphate-anions decrease the pH strongly and Cl anions have no effect on pH.
According to the Memento de l'Agronome, 4th edition, p. 155, optimal pH range for cotton is 6.5 - 7.5.

- Effect of Nitrogen.

The nitrogen is needed for the formation of new cells in the plant. The period it is needed most for cotton is the peak flowering. It is important to apply the nitrogen fertilisers in split quantities and not the whole quantity at once, since nitrogen is a mobile salt and in solution in the soil moisture it has the risk of being leached out away. Since its' pH is very low, Ammonium Nitrate of Ammonium Sulphate are better fertilisers than Urea.

- Effect of Phosphate.

The phosphate is needed for the transport of energy in the plant and the photosynthesis-process. Phosphate is an immobile salt and will be retrieved by the plant at the time it is needed most. Best is to apply the quantity at the beginning of the season. Not too much fertiliser is needed, since it is considered a "quality" fertiliser, in contradiction to N-fertiliser, which is considered a "quantity" fertiliser.

- Effect of Potassium.

Potassium is having its effect on the water balance (uptake of water by roots, transpiration) of the plant. Like phosphate, it is immobile. The K stimulates immunity against diseases and resistance against drought, through strengthening the cell wand and therefore retaining turgor rigidity. Also potassium is effecting the soil structure. It reduces the pH of the soil and therefore increases the CEC. In that way it is having a neutralising effect on the impact of sodicity. Another effect of potassium is that because of its monovalency it is a competition for the Natrium-ion and therefore slightly reduces the effect of clay dispersion. No literature was found on this topic.

- Effect of Zinc.

Zinc is a component in enzymes which play a role in plant development. Especially when growing rice it is needed to apply 10 to 15 kg of Zinc per acre. Reason for this is that the rice is cultivated with a ponding water layer, which leads to anaerobic conditions in the soil. Due to this conditions the Zinc is transformed into a solid form which can not be taken up by the roots.
Since this anaerobic conditions can also be due to a reduction of the hydraulic conductivity as an effect of sodicity, it is a hypothesis that on sodic soils with a frequent irrigation there will be shortage of Zinc, not only when cultivating rice. When Zinc is applied it should have a time lag of two weeks with the application of a phosphate fertiliser, since the phosphate and the Zinc would other wise both react into a solid which is not uptakable by the roots.

- Cotton requirements

For the three main components the requirements of cotton according to the crop stages is mentioned in Table 3.5.

Table 3.5. Nutrient requirement of cotton for different growing stages.

Time	Stage	Nitrogen	Phosphate	Potassium
days		% of total	% of total	% of total
0 to 50	Vegetative growth	6	4	6
50 to 112	Reproductive growth	92	87	94
112 to harvest	Maturation	2	9	0

Source: Soil Fertility Institute Pakistan.

The recommended total requirements, according to A.A.R.I.F. are:
- 50 kg/acre of Diammonium Phosphate (equal to 23 kg of P and 9 kg of N).
- 150 kg/acre of Urea (equal to 64 kg of N).

Fertiliser use in the Hasilpur region

Fertiliser use at sowing is low, only 16% of the total amount is applied at that time. This is not according to the recommendations of the extension service. They recommended 50% of the fertiliser already to be given at sowing time. The point is that farmers do not want to invest any money until they are sure that the crop has installed well. They do not have the financial possibilities to take a risk on this.
Before the rain no fertiliser is applied in general.
Due to the early rains the first fertiliser application was even more delayed. Most of time fertiliser is applied together with an irrigation, to ensure a good uptake of the nutrients by the plant roots, and with ploughing. This two practices were not possible during the rain. The soil was soaked already, so extra water would effect the aeration of the soil and ploughing in a wet soil deteriorates soil structure. Therefore all the farmers started with the fertiliser application after the rains of July, in the beginning of August. Especially in view of the variety which is mostly grown, CIM-240, this fertiliser application was too late. Most of the fertilisers, 43%, are applied at this time. The fertilisers which are applied most are Urea and Ammonium Nitrate. This fertilisers only supply nitrogen, so there must be a deficit on phosphate. This phosphate deficit is increased by the low organic matter contents of the soils.
With some farmers the perception is that phosphate is a fertiliser that should be used for wheat. According to the farmers it is giving 'strength to the crop', which is more important for wheat than for cotton.
Also potassium fertilisers are not used in case of cotton. Soils in the region are rich in potassium due to the river sediments and according to the Soil Fertility Institute Lahore also the tubewell water and the canal water are having high contents of potassium.
A high amount of fertilisers is applied at the end and after the flowering, 34% of the total amount. This is in contradiction with the recommendations of both Ayub and the Extension Service, that fertiliser should be applied just before and at the beginning of the flowering. Apparently farmers just wait with applying fertilisers until they see that the plant condition is deteriorating. Then the fertiliser is used to restore this deterioration again. So in general, compared to the recommendations, you can see a shift of the fertiliser application from the early crop stages to the flowering period. This is the conform the observations done by Pintus, 1995, who observed that farmers where having the same practice for wheat.
Average amount of fertiliser is 141 kg per killa for 600 Rs. per killa, ranging from 0 kg per killa for Abdul Sattar, ID 267, to 443 kg per killa at a cost of 1320 Rs. per killa for Muh. Yaqoob.

Impact of soil conditions on fertiliser requirements.

Soils in the region are having high pH. As mentioned before a high pH leads to a reduction in CEC. Therefore it is important to apply low pH fertilisers. Most farmers are aware of this due to experience and try to apply different fertilisers than DAP and Urea. Still the fertiliser suppliers sell packages of fertilisers, due to which farmers are forced to purchase also Urea when a bag of for instance Ammonium Nitrate is purchased.
Also soils in the Hasilpur region are without exception poor in Zinc (Soil Survey of Pakistan, 1996). It is assumed that this is causing problems for cotton crops, especially in case of water ponding due to sodicity.
According to the Extension Service especially sandy soils might have a deficiency in potassium and therefore need an addition for this. It is not clear if the content of potassium in the irrigation water is high enough to ensure a good supply.

3.3.4. Diseases and spray use

General

In short the three main types of diseases are:
1. the white fly, which is also the vector for
2. the curved leave virus.
3. the spotted boll worm.

The spotted boll worm is ready to attack all year. The white fly favours a high temperature and a high humidity so it attacks from July and onwards, during the rainy period. Especially the white fly is very difficult to control. The effect of the white fly during the vegetative growth is that it sucks the cell sap so the plant dries out and photosynthesis stops. Therefore the first spray is needed already during the vegetative growth.
The second spray is to protect the bolls. The larvae of white fly pour into the bolls, accompanied by the spotted boll worm, and some others like the heliothis and the pink boll worm. They also eat the end of flowers, damage the top of the plants and even eat the stem, especially the spotted boll worm. If bolls are eaten they damage the cotton seed and the bolls will not open.
Virus diseases, especially the curved leave virus, are also transmitted by white flies. The symptoms of virus are small leaves and thick, dark green veins, which are blocked due to multiple cell growth. The veins are blocked and the transport of nutrients and photosynthesis products stops. A sign of a severe virus attack is the formation of a small leave under the normal leave. This attack can start at any stage. The white flies are protected by vegetation, so their attack will be more severe close to bushes, forests and gardens.
According to Master Aslam there are 36 types of viruses and 6 types of white fly. A virus can be detected from the beginning. They notice the bad plants at the first irrigation. The white fly attacks when the cotton is about 3 feet high and is very difficult to control. So this has to be controlled from the beginning. He did 8 sprays. The only information they have is from the chemical companies, while most of the people can not read.
Susceptibility to a virus attack increases from NIAB-78 to CM-109 to CM-240. The most resistant variety is the Desi-cotton.
There is a wide variety of sprays available to combat diseases. Still there was no information readily available about the quality of sprays and the contents of it. This is mainly due to the fact that the spray market is a relatively young market and a very commercial one, so little investigations are carried out by the Pakistani research institutes.

Diseases and spray use in the Hasilpur region

Luckily the virus attack did not fleer up epidemically this year. Still a lot of farmers complain about the virus being the major yield decreasing factor. White fly attack started at the end of July.
There is only one farmer who applied a spray already in the beginning of the season before the showers arrived.
Before flowering, in August, the first spraying starts. The farmers who spray at this moment try to be a little ahead on the diseases or faced some problems with diseases already. About 30% of the spray is applied at this time. This is a low percentage. Probably the farmers wait with spraying in the hope that the attack will not be very severe. For this year that can be considered as a miscalculation.
At flowering time most of the spraying (69% of the total amount) is done.
Average amount of sprays is 2.3 litre per killa for 920 Rs. per killa, ranging from 0 litre per killa for Abdul Sattar, ID 267 to 4.75 litre per killa for 1633 Rs. per killa for Muh. Islam. The costs of spray are exceeding the fertiliser costs.
Still for almost half of the sample fields (27) the virus attacks is recorded to be high. For most of the farmers it is difficult to judge which spray to use in which situation. Information from the Extension Service is not readily available and the information on the bottle itself they can not read themselves. Also here the role of the shop keeper is important.
As mentioned before it is difficult to analyse the impact of the spray use and the diseases. Besides a lack of information the main reason for this is that a virus attack can not be controlled by one farmer alone, but more on a regional or even watercourse scale. Farmers were complaining that they were using enough spray, but their neighbour would not use spray, so the virus attack spread from the neighbours field to the farmers field.

3.4. Effects of water supply on cotton

General

About the irrigation water supply for cotton disagreement consists in the literature. Reason for this is that the water demand of cotton is specific for a region and the cultivar that is investigated. Water-yield production functions that have been developed by Grimes and El-Zik show

$$Y(ET) = -3419 + 919.6 * ET^{1/2} - 42.71 * ET$$

with: Y(ET) = *Cotton lint* yield in kg/ha
ET = Evapotranspiration in cm, $25 < ET < 100$

From this it is clear that the yield is not linear related to the cotton yield. Also Kuper, 1989, showed that

$$Y(W) = -2690 + 24.44 * W - 0.0189 * W^2$$

with: Y(W) = *Seedcotton* yield in kg/ha
W = Total water application in mm (application to the rootzone by means of localised irrigation); $290 < W < 740$

Note: Yield noted in different plant components

So from the quadratic function form it is observed that due to over irrigation yields can decrease due to an reduction in soil aeration. Mostly it is economically more profitable if a slight water deficit is tolerated for the plants (Roscher, 1994.). A small excess of water can cause yield reduction and costs money at the same time. Conform this statement it is observed for the 2 water production functions that a maximisation of water use efficiency is achieved in case of an ET of 55 cm with an Y(ET) = 1052 kg/ha and an W of 377 mm with an Y(W) = 3844 kg/ha[13]. A maximum yield though would be achieved in case of an ET of 116 cm (*Note:* Not within boundaries of ET as researched) with an Y(ET) of 1531 kg/ha and a W of 647 mm with an Y(W) = 5211 kg/ha.

The total water requirement of cotton in the Punjab is ranging from 600 mm to 650 mm, depending on the variety and the climatic conditions.
For the Punjab the recommended irrigation sequence is:

- Pre-emergence irrigation

Kacchi rauni of 75 mm (3")
Pakki rauni of 100 mm (4")

The pre-emergence irrigation is done in order to ease soil tillage and to fill up the maximum rootzone of the cotton. Later in the season the weather will be too hot, so evapotranspiration too high, to apply water to a sufficient depth.

- Vegetative growth

Then after 40 to 50 days after sowing the irrigation supply starts with a sequence of 15 days, 75 mm each time, 2 to 3 applications until flowering.

- Flowering

At flowering the irrigation water requirement increases so an irrigation each 7 days of 50 to 75 mm has to be applied.

At the end of October the irrigation should be stopped in order to enhance the bolls maturation so that the cotton crop can be harvested before the 15th of November and the wheat can be sown.

The most waterstress sensitive period for the indeterminate variety CM-109 according to Malik et al. of the C.C.R.I.M. is the squaring period followed by the early flowering.

<u>Irrigation in the Hasilpur region</u>

The average irrigation application is 740 mm, ranging from 210 mm for Muh. Irshad at Azim 20-L to 1330 mm for Muh. Islam at Fordwah 130-R.
The lowest water applications are applied at the watercourses Azim 20-L and Fordwah 130-R. At Azim 20-L a major part of the crop water requirement is supplied by capillary rise from the

---

13 *This point of maximum water use efficiency can be found by solving ET/W from the equation:*
*Y(ET/W)=[dY/d(ET/W)]*ET/W.*
So: $-459.8*ET^{0.5} = -3419 \Rightarrow ET = 55\ cm \Rightarrow Y(ET) = 1052\ kg/ha$
and: $-0.0189*W^{2} = -2690 \Rightarrow W = 377\ mm \Rightarrow Y(W) = 3844\ kg/ha$

groundwater at 150 cm from the soil surface. At Fordwah 130-R farmers face a bad water availability, due to low canal water supply, low cash availability and bad tubewell water.
The high water applications can be found at Azim 111-L and Fordwah 46-R and 62-R. At Azim 111-L the tubewell water availability is high due to the high cash availability of the farmers and the good tubewell water.
The variation in water applications is the highest in Fordwah 130-R. This is mainly due to the different characteristics of farmers, i.e. tubewell ownership, soil types, salinity features and cash availability. At this watercourse a lot of small water quantities are applied, up to 14 applications.
At Azim 111-L and Azim 20-L this applications are less, 6 to 7. At Azim 111-L the soils are more loamy, with higher water retention capacities (± 180 mm/m), so big quantities, up to 20 cm to fill the rootzone, can be applied at once.
A main problem concerning irrigation in the area is the low water retention capacity of the soils. Therefore it can be observed that for a lot of farmers the irrigation application efficiencies are low, due to leaching. This is especially the case at the sandy soils of Fordwah 46-R, 62-R and 130-R.
At 70% of the fields an accumulation of salts in the profile can be observed. From this fields 49% is situated at Fordwah 130-R and 30% at Azim 111-L, where 59% of the sample fields is located at this watercourses.
Especially on the fields with little water applications no salt accumulation occurred. Most of the applied salts are leached out by rain. Also at the fields with high water applications salt accumulation was low, due to leaching.
On average the cotton was transpirating at 80% from its' maximum. The most sever waterstress occurred during the period of bolls maturation. Since the total water application is higher than the potential evapotranspiration of the crop it can be observed that overall water use is not efficient. Probably the main cause for this deficiency is the fact that water is not available at the time that it is requested.

3.5. Effects of organic matter.

General

In general the organic matter content increases with the % clay of the soil. It is normally between 1.5 and 2 % in a soil under cultivation, even without the application of farm yard manure (pers. comm. P. Garin). The organic matter content in the soil is related to the alkalinisation of the soils, so high pH values. This is related to a very high ratio Na-ions/CEC.
At high pH values the organic matter is dissolved, soil structure is completely destroyed and on the surface a black crust of Sodium Carbonate occurs (pers. comm. S. Marlet, CIRAD).
In table 3.6. a classification of organic matter contents for soils with 15 to 50% of clay plus silt at different pH-values.

Table 3.6. Classification of organic matter contents.

Organic Matter content in % (0 - 20 cm and below)	**pH**	
	4 to 4.5	>7
Very low	0.43	0.17
Poor	0.76	0.43
Medium	1.35	0.76
Quite good	2.55	1.35
Good	5.1	2.55
Exceptional	10.1	5.1

Source: Memento de l'Agronome, p. 153.

A deficit in low organic matter contents has two consequences:

1. A reduction in structural stability, which is related to both sodicity and a deficit in organic matter contents.
2. A deficiency in nutrients, particularly in phosphate as is shown in Figure 3.2.

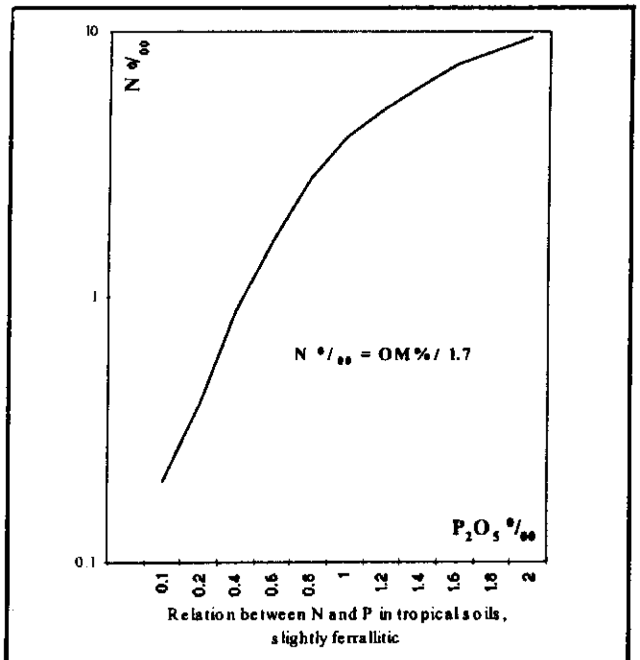

Figure 3.2 Relation between N and P in tropical soils.
Redrawn from Memento de l'Agronome, p. 154, after Dabin, 1963

<u>Organic matter in the Hasilpur-region</u>

According to the measurements done by the Soil Survey of Pakistan in the area organic matter contents in the area are very low to medium. As mentioned above this is having implications for the structural stability of the soils and therefore the workability and the supply of nutrients. For all the soils pH-values are greater than 8, that is to say that alkalinisation occurred and organic matter contents decreased. One way for the farmers to mitigate this problem is by applying farm yard manure on their fields. This is practised indeed by 60% of the farmers. The quantities that are applied are in the range of 5000 to 9000 kg/acre. With this amount it is possible to maintain the organic matter content[14]. The effect of farm yard manure is the strongest one year, so two growing seasons, after the application. It increases the workability, the infiltration rate and the fertility of the soil. It is also used to mitigate the effects of salinity and sodicity, since it decreases the pH-value.

All the farmers report to apply farm yard manure to their good fields, i.e. with a mera soil, so not on fields which are performing poor. So 58% of the fields never receives any farm yard manure. Apparently the effect of farm yard manure on mera fields is greater than on sandy fields.

---

14 *Assuming a quite good o.m. content of 1.5% in the top 20 cm of the soil and a bulk density of 1.6 gr/cm^3, 48 T/ha o.m. is present. Assuming a mineralisation of 2% (for tropical soils) per year, 960 kg/ha is mineralised every year. Depending on the water and organic matter content of the farm yard manure, manure applications of 2.7 T/ha (o.m. 35%) to 3.5 T/ha (o.m. 27%) per year are necessary to maintain the same o.m. content.*
To increase the o.m. content from 0.5% to 1.5%, 16 T/ha o.m. is needed, so an application of 60T/ha of farm yard manure of good quality (o.m. 35%). On sandy soils mineralisation of o.m. is in the order of 3-4% per year, so higher applications are needed to maintain the o.m. level.

Also farm yard manure is not applied very often. On average the fields which received farm yard manure had their last application 2 years ago.
None of the farmers purchases farm yard manure.

3.6. Effects of saline and sodic conditions

General

Salinisation is a global term used to describe different processes such as **salinisation sensu strictu, alkalinisation** and **sodication**. These processes are linked with each other. Salinisation involves **hydrological** (soil water flow), **geochemical** (precipitation of minerals and chemical exchanges between soil and soil solution), and **physical** (degradation of soil structure) processes (Condom, 1996). Salinisation sensu strictu is referred to as salinisation in this report, since this is a common habit in literature.

- Salinisation

Salinisation is an accumulation of salts in the soil profile, without an exchange of ions between the soil water and the soil particles. No exchange is occurring since there is no imbalance between Calcium and Natrium ions. The most commonly used chemical indicators to characterise the concentration of salts in the soil and therefore the degree of salinisation is the Electrical Conductivity of the soil water (**EC_e**),expressed in dS(iemens)/m. The EC is related to the ions which are present in the solution. For EC values up to 2 dS/m the following relation is verified (Appelo and Postma, 1995):

$$\Sigma anions(meq / l) = \Sigma cations(meq / l) = 10 \times EC(dS / m)$$

Note: In this study use was made of EC_e measurements.

- The main effect of salinity is an *increase in the osmotic potential ($\psi_{osmotic}$) of the soil water* and therefore an decrease in the water uptake by the plant. This increased osmotic potential is the effect of the high concentrations of ions in the soil moisture. A high concentration of ions is most apparent in regions with a high groundwater table, where salts are deposited in the rootzone by capillary rise from the salt-rich groundwater.
- A second effect of salinisation is the *toxicity* of specific ions. It can be caused by an accumulation of magnesium ions. It is recognised by black to dark green areolas on the soil surface. Due to the high concentration of the ions the plant is penetrated and ion-disfunctioning is caused. this is toxic for the plant and it can evolve towards sodicity (Lauchli and Epstein, 1990).

Cotton is qualified as a salt-tolerant crop. Normally soils are considered saline if the electrical conductivity of the saturated extract (EC_e) exceeds 4.4 dS/m. Initial yield decrease for cotton is observed at an EC_e level of 7.7 dS/m with a yield reduction of 50% at an ECe of 17 dS/m (Ayers, 1977).
Still lower salinity levels decrease both the transpiration and the photosynthesis of the crop and so decrease the water use efficiency, since irrigation frequencies should be higher. Latif and Khan, 1976, found that the most sensitive stage in the cotton development for salinity was the germination. In later stages the cotton is showing ontogenetic changes with make the crop more tolerant to salts. According to Tanji (ed.), 1990, it is still unknown what these changes are.

A research carried out by Malik et al. on 12 cotton cultivars commonly used in Pakistan show that the germination rate, i.e. number of germinated seeds/total number of seeds, at an EC_e of 3 dS/m is 88%, at an EC_e of 4 dS/m is 80% and at an EC_e of 12 dS/m is 50%.
From this point of view cotton seeds in the Hasilpur region are not directly affected by salinity, since the EC_e ranges from 1 to 3.5 dS/m with very few plots having an EC_e up to 6.4. (Soil Survey of Pakistan, 1996). Still, this measurements done on the 62 sample fields have been done shortly after sowing, at the end of June 1995. Purpose of farmers is to wash out all the salts before sowing, so therefore average EC_e's over the growing season are probably higher.

- Alkalinisation.

Alkalinisation, a geochemical process, is characterised by an increase of alkalinity and consequently a rise of the pH of the solution. The alkalinity of a solution can be defined as the group of anions which may accept protons (Bourrié, 1976). Alkalinity is mostly due to the carbonate species HCO_3^- and CO_3^{2-} (Valles, 1985). For alkalinity different indicators are distinguished for different features of the alkalinisation process. In this study use was only made of pH measurements, since the main effect of alkalinisation is the increase in pH. This can be mitigated by the potassium-ions (pers. comm. K. Gill).

- Sodication

Sodication is a process of exchange between sodium (Na-ions) in the solution and divalent cations (mainly Ca^{2+}), adsorbed on the exchange process. In this process the amount Na-ions is increasing relative to other cations. It is a geochemical process, like alkalinisation, but next to this it is also a physical process, since it leads to degradation of the soil structure. Two indicators for sodication are used commonly:

1. The Sodium Adsorption Ratio (SAR), expressed in $(meq/l)^{-0.5}$, which is defined as follows (USSL, 1954):

$$SAR = \frac{Na^+}{\sqrt{\left(Ca^{2+} + Mg^{2+}\right)/2}}$$

Na^+, Ca^{2+}, Mg^{2+} in meq/l

Also a adjusted SAR, as proposed by Suarez (1981) and Ayers and Westcots (1985), is common used as an indicator for irrigation water.

2. The Exchangeable Sodium Percentage (ESP), expressed in %, which is defined as follows:

$$ESP = 100 \times \frac{\left[Na^{2+}\right]}{CEC}$$

With CEC = Cation Exchange Capacity.

In this study use was made of SAR measurements.

Several effects of sodication are distinguished.

- The Na-cation creates dispersion of the clay particles and thus micro and even macro pores are destroyed, as is soil structure. Clay particles are peptizised, i.e. dissolved from the A-horizon and transported to the B-horizon of the soil. This leads to a strong decrease of the hydraulic conductivity and infiltration rate. The rootability is deteriorating and so is the aeration of the soil.

Aeration of the soil especially becomes a problem in case the field is irrigated frequently. In that case the water will be ponding on the field for a prolonged time. As mentioned before, this decrease in aeration can have a negative impact on the availability of Zinc. Also a decrease in aeration decreases the water uptake of the crop roots, since a percentage of air should be present in the soil. So the soils become infertile because of leaching of the organic matter and clay particles to the lower soil layers. This can cause the formation of a hardpan in the soil, i.e. an impermeable layer in the subsoil.

- The swell and shrink properties of clay soils are increased in case the Na-ions are bound to a clay particle. This effect is mitigated by a high electrolyte concentration of the soil water. In other words, soil physical properties will deteriorate in case of low salt concentrations and relative high proportions of sodium and good physical soil properties will occur in case of high salt concentrations and relative low proportions of sodium.
- It is reported by Yadav, 1987 that cotton is sensitive at germination stage for proportionaly high amounts of sodium

The application of Gypsum can help to avoid or possibly alleviate problems with reduced infiltration rate and seedling emergence. Gypsum increases the salt concentration of the infiltrating water and supplies divalent calcium to replace sodium. But irrigating while adding Gypsum is having the danger of creating a compacted layer in the sub-soil. Due to the sharp infiltration front of calcium-saturated water the sodium particles will be transported to the subsoil and will form a compacted layer before being leached out.

Salinity and sodicity in the Hasilpur-region

The impact of sodicity is assumed to be bigger. All the farmers, except from Shakar Ali and Muh. Irshad at the head-end watercourses, reported to face problems related to salinity and sodication. Especially on the watercourse were only tubewell water is used, Azim 111-L farmers complain about low hydraulic conductivity's. Other farmers complain about decreasing yields and the fact that the irrigation frequency has to be higher when using tubewell water, so-called 'dry'-water. SAR-values of the saturated extract range from 0.11 for Muh. Irshad, close to the Azim- distributary and 13.27 for Muh. Youssaf at Fordwah 130-R.
Still, gypsum is not available on the market and farmers look for other means to mitigate salinity. the most apparent practice is to use tubewell irrigation water as little as possible. Especially at germination farmers try to avoid the use of low quality water. In case canal water is not available farmers will rent a tubewell with good quality water from a neighbour. To prevent moisture stress due to an increased $\psi_{osmotic}$ farmers will increase their irrigation frequency, in order to stay within the range of readily available moisture.
Other practices that are under taken are:

- Application of farm yard manure.
- Use of low pH-fertilisers, like SSP, Ammonium Nitrate and Ammonium Sulphate.
- Creation of furrows and ridges, to bring the salts on the surface away from the crops.

3.7. Cotton yield

General

Compared to the revenues of the intensive cultivation in regions like Israel, California and Australia, which are in the order of 3000 - 4500 kg seed cotton/ha, Pakistani yields are low. It is reported by Akhtar, 1991, that for 1991 the average production for cotton was 607 kg seed cotton/ha.

The fibre represents around 35% of the total seed cotton (Memento de l'Agronome, 3rd edition, p. 870)

Cotton yield in the Hasilpur region

- Pickings

All the pickings in the region were done manually by lady pickers.
The flowering period takes about two months and around the beginning of October, when the bolls of the first flowers have matured, the pickings start. First pickings are normally small. The length of the picking season is on average 52 days, so until the end of November, beginning of December. Fields with good yields are normally left a little bit longer on the field, to get the optimal result of cotton. Farmers are aware of the necessity to sow wheat early but due to two reasons the harvest of cotton is delayed:

1. Cotton is as cash crop, it requires a lot of inputs and a small pick of some 10 kg already pays back a bag of fertiliser. So it is profitable to leave the crop on the field in order to get the last bits of cotton.
2. The last pickings are normally small. The lady pickers refuse to come when the expected yield is low, because they normally get paid in a share of the yield. This ladies try to optimise their share, because it is the main source of income for the women during the year. They try to delay the last pickings. Paying the ladies with money is not an option, because the quality of their pickings will go down and the cotton sells for less at the ginnery.

- Yields

The average yields obtained on all the fields is 1030 kg/ha. This is ranging from 16 kg/ha for Abdul Sattar, ID 267, to 2750 kg/ha for Muh. Yaqoob, both at the same watercourse.
The five best yields and the five worse yields and the main causes for this yields are mentioned in Table 3.7.

Table 3.7. The main causes of best and worse yields.

Farmer	Plot	Yield (kg/ha)	Probable causes
Abdul Sattar, ID 267	97/02/05	15.9	1. No canal water available at sowing, so sowing delayed, germination destroyed by rains and a hard soil due to sodicity. 2. Harvested early.
Abdul Sattar, ID 267	97/02/14	104.6	1. No canal water available at sowing, so sowing delayed, germination destroyed by rains and a hard soil due to sodicity.
Muh. Sid. Haleem	351/16/20	167	1. Late sowing, so germination destroyed by rain and ponding water.
Muh. Yaqoob	76/16/20	229	1. Only one year under cultivation, formerly sand dunes. 3. Intercropping with fodder, so competition for water.
Muh. Sid. Haleem	351/16/12	316	1. Late sowing, so germination destroyed by rain and ponding water. 2. Heavy virus attack.
Haji Elahi Baksh	410/11/15	2022	1. Sugarcane-cotton sequence and inputs remain in the soil. 2. Farm yard manure 1 season ago 3. Bhari mera soil. 4. 12 Ploughings before sowing.
Ghulam Hussain	173/15/21	2058	1. Good seed, S-14 2. No waterstress 3. No virus attack.
Muh. Irshad	506/15/23	2426	1. Bhari mera soil 2. No waterstress 3. No virus attack.
Shakar Ali	550/09/11	2443	1. Good seeds and good germination 2. No waterstress 3. High manual labour input 3. Bhari mera soil
Muh. Yaqoob	76/16/15	2748	1. Soil were "a dead man can grow" 2. Farm yard manure 1 season ago. 3. Good seed, S-14.

3.8. Validation and restitution of the research results.

- Understanding of technical sequence.

For all the farmers it appeared that the interpretation of the technical sequence was mostly correct. One thing which became clear was that quite some important data were missing concerning inputs, irrigation and labour. This was the case for all the farmers. By discussing the technical sequences essential additional information was obtained about the farmers behaviour and the factors which influenced his decisions. For instance information was obtained about specific reasons to use a certain fertiliser, cultivate certain varieties or perform extra irrigations. A good impression of this information will give the elaboration of the restitution enclosed with the farmers description in Annex 11, 16, 18 and 19.

- Discussion of alternatives.

The discussion of the alternatives was not very fruitful for the farmers. Alternatives that were presented to the farmers were already known and appeared to be not achievable within the constraints of the farmers and the institutional constraints of the farmers. A good insight was achieved on which way the farmers obtain their information about good varieties and new practices. Most of the practices are based on the experience of farmers of what is working out best on their fields.
New practices are being spotted by closely watching the activities of other farmers. Certain farmers in the area perform a role as risk-takers and any success they have with a new variety or some new techniques is being copied first on a small scale by other farmers.
Confronted with knowledge obtained from this research farmers reacted sceptic and were not willing to give it a try. This becomes clear looking at the case of Qazi Muh. Ali.
At his farm the problem of a hard-pan formation, due to long-term tractor use, leading to a low hydraulic conductivity, and a zinc-deficit was identified. The hard-pan formation was confirmed by soil samples. Two suggestions were formulated:

1. Perform a ripping at the fields
2. Try the effect of the application of some Zinc Sulphate, normally only used for rice, on the cotton crop.

Ali was aware of his problem of a low hydraulic conductivity. It was getting worse and worse and this year he had the worse yields ever, both due to the rains and the ponding water and the virus. He was thinking about solving it by importing sand from other watercourses. By mixing his soil with sand the infiltration rate would be increased. To perform a ripping would be to costly for him, since he also would need to leave the plot fallow for a while afterwards. Clearly it was not only the costs but also the hassle of all the activities which did not please him. He had also tried to discuss his problems with the people from the extension service, but their knowledge about farm management was not validated high by him.
Qazi Muh. Ali did not seem to be really interested in the research results and the possibilities of changing his farm management for cotton. There was a lack of a real discussion about the alternatives due to this reason.

- General Impression

The farmers confirmed the average sequence presented to them very easily, raising the impression they did not want to contradict in order to save time. Still farmers were willing to talk and share their knowledge.

The problem was that the restitution was done when the farmers were harvesting the wheat and at the same time showers could appear. So farmers were quite in a hurry to harvest the wheat, before a rain could do it any damage.

CHAPTER 4 PRODUCTION FUNCTION

4.1. Determination of input parameters

The factors used in the production function are divided in five groups:

1. Soil
   - Soil texture
   - Salinity status
2. Waterstresses
3. Input consumption
   - Seeds
   - Fertilisers
   - Sprays
   - Farm yard manure
4. Labour input
5. Machinery use

Where possible these groups were divided in components and according to the timing of the practices in the growing season. For instance, the number of ploughings before the seedbed preparation, the hours of labour per killa in the vegetative growth, the amount of nitrogen applied after peak flowering or the average pH of the fertiliser applications.
On the water side for each growing stage the waterstress was determined, and other factors like the salt accumulation in the profile or the leaching from the profile.
In total 175 parameters were determined.

4.2. Production function

The following parameters appeared to have significant impact on the dependant variable YRATIO, i.e. Y_{act}/Y_{max}, where Y_{max} was taken 3000 kg/ha . The results of the statistical analysis are displayed in Table 4.1.

SOWDATE	=	Delay in sowing after May 15.
SRNITTOT	=	Square root of the total nitrogen used (in kg/ha)
MANURE	=	Time since last farm yard manure application, in a coded form to take in to account that farm yard manure has maximal effect after two seasons.
SQ(SAR6>8)	=	Square of the SAR of the top 6" of the soil above a critical level of 8.
SRTATPEF	=	Square root of the T_{act}/T_{pot} during the stage of early flowering.
SRSPAFJU	=	Square root of the time elapsed after July 25 and the next spray.

Table 4.1. Results of the statistical analysis.

Variable	Parameter estimate	T for H_0; Parameter = 0	Prob > |T|
SRTATPEF	0.471	4.233	0.0001
SOWDATE	-0.004	-2.607	0.0121
SQ(SAR6>8)	-0.007	-2.402	0.0202
SRSPAFJU	-0.031	-2.334	0.0238
SRNITTOT	0.023	2.232	0.0303
MANURE	0.046	1.1678	0.0998

Dependent variable: YRATIO
R-square = 0.8747
Adjusted R-square = 0.8590

Taking into account a (Prob > | T |)< 5% for the production function, so MANURE is not considered., the following production function could be established:

$$Y = 1413 * \sqrt{TATPEF} - 12 * SOWDATE - 21 * (SAR6 > 8)^2 - 93 * \sqrt{SPAFJU} + 69 * \sqrt{NITTOT}$$

The best fit was realised without a constant value. It can be observed that the R-square and the adjusted R-square are very high.

- The biggest impact on the yield is established by a reduction in transpiration during flowering. This stresses the need for an irrigation short after the rains. In literature (Grimes and El-Zik, Malik et al.) it is stated that the most sensitive period for waterstresses is the squarring period followed by the early flowering. For the sample fields the squarring period mostly coincides with the rainy period in the month of July, so little waterstresses occurred at that time.

- The date of sowing, as expected, proved to have significant impact on the yield. Any delay in sowing causes yield reductions. One major effect this year was probably the early rains at the end of June, which ruined the crop.

- SAR in the topsoil was having impact beyond the critical level of 8. Most probably this impact occurs during the germination stage of the cotton. It might be a toxicity of the Na-ions or the impact of a low hydraulic conductivity at that time.

- From the production function it becomes clear that it is essential in order to mitigate the virus attack to apply a spray right after the first occurrence of the fly. The July 25 cut-off point was chosen after observations done by Garin (CEMAGREF) during a field visit in July 1995.

- The application of N, in the form of Urea, Ammonium Nitrate, or other nitrogen fertilisers proved to have impact.

- Even though manure was marginally significant it can be observed that yields can increase substantial by manure applications. Problem with manure data was that they had not been monitored and quite some farmers were not able to recall the last time they had applied manure on a plot.

Surprisingly the impact of the soil can not be retrieved by this statistical analysis. This is probably due to the collinearities between the variables. A crop with a good soil, gets sowed earlier, has a better germination, receives more fertiliser, spray and irrigation. The same counts for labour.
The application of phosphate fertiliser did not prove to have impact. This is probably due to the fact that high nitrogen applications are combined with high phosphate fertilisers, so its' effect is taken into account by the NITTOT-variable.

To demonstrate the usefulness of this function, for instance a T_{act}/T_{pot} during early flowering of 0.8 would decrease yields with 150 kg/ha. Sowing delay of 10 days would decrease yields with 120 kg/ha. One bag of Urea, containing 23 kg of N, would increase yields with 331 kg/ha.
And a sodic soil, having a SAR of 12, so 4 above the critical level of 8, would decrease yields with 336 kg/ha.

CHAPTER 5 RELATING FARMERS' PRACTICES TO THEIR TYPOLOGY

5.1. Analysis

The analysis in this chapter is based on the creation of three average sequences in order to evaluate the overall cotton cultivation strategy. This cotton cultivation strategy, were the focus switches from the field level to the farm level, is explained from two view points:

- Farm characteristics, related to the typology as described in Chapter 1.5.
- Intra-farm water allocation, i.e. the impact of the water allocation to other crops on the water allocation to cotton.

The analysis is schematised in Figure 5.1.

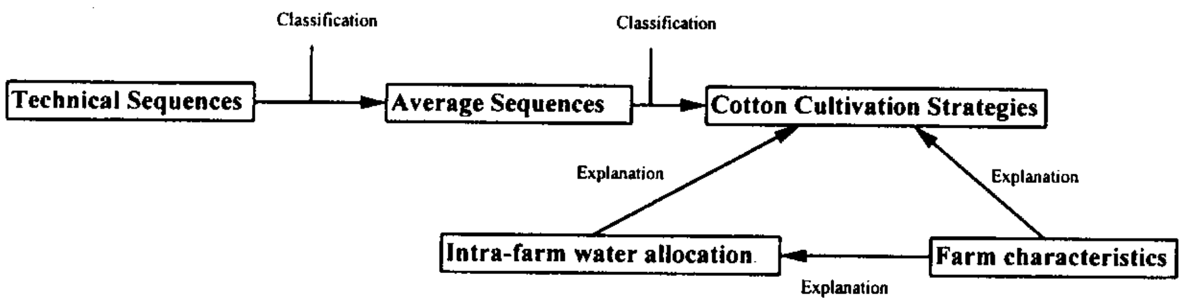

Figure 5.1. Analysis of cotton cultivation strategies.

In this chapter the different sequences and strategies are discussed. For each sequence an example technical sequence is displayed and an example intra-farm water allocation is discussed.

5.2. Average sequences

Based on the main factors that determine the yield, as shown in Chapter 4 with the determination of the production function, three main sequences leading to different yield levels, could be identified, displayed in table 5.1.

Table 5.1. Average sequences

Sequence	**1**	**2**	**3**	*Unit*
Sowing time	May 1 - June 7	May 1 - June 7	After June 7	
Waterstress at early flowering	100 - 80	80 - 50	80 - 65	T_{act}/T_{pot} (%)
Timing of first Spray	0 - 20	25 - 100	20 - 50	*Days after July 25*
Nitrogen use	50 - 100	0 - 50	0 - 50	*kg/ha*
Yield level	Medium to high	Low to medium	Low to medium	

It will be clear that this classification is a rough simplification of all the sequences that have been investigated

Now it is observed that farmers use several different average sequences within their farm. In Table 5.2. a list is given of the sequences that each farm uses.

Table 5.2. Average sequences used per farm.

Group	Farmer	Sequence 1	Sequence 2	Sequence 3
Group 1	Bashir Ahmad	X	X	-
Group 1	Muh. Siddique Haleem	-	X	X
Group 2	Shakar Ali	X	-	-
Group 3	Muh. Irshad	X	-	-
Group 4	Abdul Sattar 267	-	X	X
Group 4	Muh. Youssaf	-	X	X
Group 6	Abdul Sattar 208	X	-	-
Group 9	Barkat Ali	-	-	X
Group 9	Haji Elahi Baksh	X	-	-
Group 9	Muh. Yaqoob	X	X	X
Group 10	Ghulam Hussain	X	-	-
Group 10	Muh. Nawaz	X	-	-
Group 11	Qazi Muh. Ali	X	-	-
Group 11	Muh. Islam	X	-	X

Based on the sequences that are used by farms, three main cultivation strategies can be distinguished. Each of them is having a subdivision according to the way they are used within the different farm types. This strategies are:

1. *Intensification by high water consumption and high input consumption.*
   - By high tubewell water consumption.
   - By high consumption of tubewell water, canal water and capillary water.
2. *Intensification by high water consumption and low input consumption.*
   - By tubewell water use.
   - By canal and tubewell water use.
3. *Extensification*
   - Diversification
   - Extensification

The strategy per farm is displayed in table 5.3.

Table 5.3. Cotton cultivation strategies per farm.

Farm strategy		Intensification by high water consumption and high input consumption		Intensification by high water consumption and low input consumption		Extensification	
Group	Farmer	Tubewell water	Canal water and tubewell water	Tubewell water	Canal water and tubewell water	Diversifi cation	Extensifi cation
Group 1	Bashir Ahmad	-	-	-	X	-	-
Group 1	Muh. Siddique Haleem	-	-	-	-	-	X
Group 2	Shakar Ali	-	X	-	-	-	-
Group 3	Muh. Irshad	-	X	-	-	-	-
Group 4	Abdul Sattar 267	-	-	-	-	-	X
Group 4	Muh. Youssaf	-	-	-	-	-	X
Group 6	Abdul Sattar 208	-	-	X	-	-	-
Group 9	Barkat Ali	-	-	-	-	-	X
Group 9	Haji Elahi Baksh	-	-	-	X	-	-
Group 9	Muh. Yaqoob	-	-	-	-	X	-
Group 10	Ghulam Hussain	X	-	-	-	-	-
Group 10	Muh. Nawaz	X	-	-	-	-	-
Group 11	Qazi Muh. Ali	X	-	-	-	-	-
Group 11	Muh. Islam	-	-	-	-	X	-
	Description in:	*5.3.1.*	*5.3.2.*	*5.3.3.*	*5.3.3.*	*5.3.4.*	*5.3.5.*

It is remarked that:

- None of the farmers follows the strategy of irrigation with only canal water.

- The strategy of intensification by water consumption and low input consumption and the strategy of extensification reflect in fact the inability to intensificate with both water and inputs.

- Since most of the farmers cultivate one or more fields with sequence 1, leading to good yields, it is apparently the practice to select at least one good field within the farm to intensify the practices there.

5.3. Relating the average sequences to the farm typology

5.3.1. Intensification by tubewell water and high inputs application

This strategy is followed by three farmers at Azim 111-L, Qazi Muh. Ali, Ghulam Hussain and Muh. Nawaz, for similar reasons.

- *Strategy related to farm characteristics*

Their main characteristics are

- No canal water supply, so high tubewell water use.
- Highly mechanised..
- Large landholdings.
- Soils with saline and sodic properties
- Large investment capacity.
- Low labour availability
- Market-orientated

- Tubewell water use.

Due to the high water availability the sowing date is not delayed Since the expected canal water supply is already zero, the farmers know that they have to perform the pre-soaking irrigation with tubewell water. Since tubewell water supply is secure, farmers can recover the soil moisture content easily in case of early waterstress. The best tubewell from the surroundings is picked for the irrigation activities, with an EC of 0.7 dS/m. Still the prolonged tubewell irrigation leads to SAR's of 6-7 on average. Also during Kharif'95 salt accumulation was high. The high amount of water applied to the field is giving some leaching, but SAR and EC-values are expected to rise within time.

- Mechanisation in combination with saline and sodic properties

The prolonged tractor use for Qazi Muh. Ali and Muh. Nawaz, 20 years, has lead to a compaction of the soil at a depth of 50-60 cm due to the weight of the machinery. This hard-pan formation leads to a decrease of the hydraulic conductivity and aeration of the soil. This process is of course enhanced by the sodic properties of the soil, leading to swell and shrink and the peptization of clay.

The input consumption is high of both spray and fertilisers. For all the fields the same quantities are applied. The fertilisers are applied at a point that the plant is in good condition and therefor do not solve a restoring purpose. Due to the high cash availability the farmers can respond quickly to the virus attack and spray is applied very early after the first attack.

There is a high homogeneity in practices due to the large landholding size and the deficit in labour. There is too little available labour of the farmer himself to consider the practices of each field especially. The farmer with the smallest landholding, Muh. Nawaz, is diversifying more in fertilisers that are applied.

Qazi Muh. Ali is renting out land while Muh. Nawaz and Ghulam Hussain are renting in land in addition to their own fields. Both reach around the same cultivated level, around 20 killas. One additional effect is that labour is always hired to perform weedings and hoeings and that a lot of emphasis is being put on machinery use.
The cotton yields obtained with this strategy are medium high in the order of 1250 kg/ha. Despite the high level of inputs and water the yield is depressed by the negative impacts of the hard-pan formation, the low hydraulic conductivity and the sodicity. It is a hypothesis that also a Zinc deficit is depressing the yields. Still due to the large landholding size the total farm income is high.

Table 5.4. Technical Sequence Ghulam Hussain, Plot 173/15/21

Seedbed Preparation	Rauni	Sowing	Irrigation	Manual Labour	Mechanical Labour	Fertiliser	Spray	Yield	SAR6
4x ploughing. 1x levelling	2 times, 200 mm total tubewell water.	May 28 CM-240	1 Irrigation before the rains. At flowering one irrigation each 10 days. 1070 mm tubewell water.	One small hoeing before the rains. One hoeing after the rain. 60 hr/ha total	One weeding with a ridger before the rains. 2.2 hr/ha total	1 bag of Urea, 2 bags of Ammonium Nitrate during flowering	First spray July 31. 3 sprays, in total 3600 ml	5 pickings; 2000 kg/ha	7-8

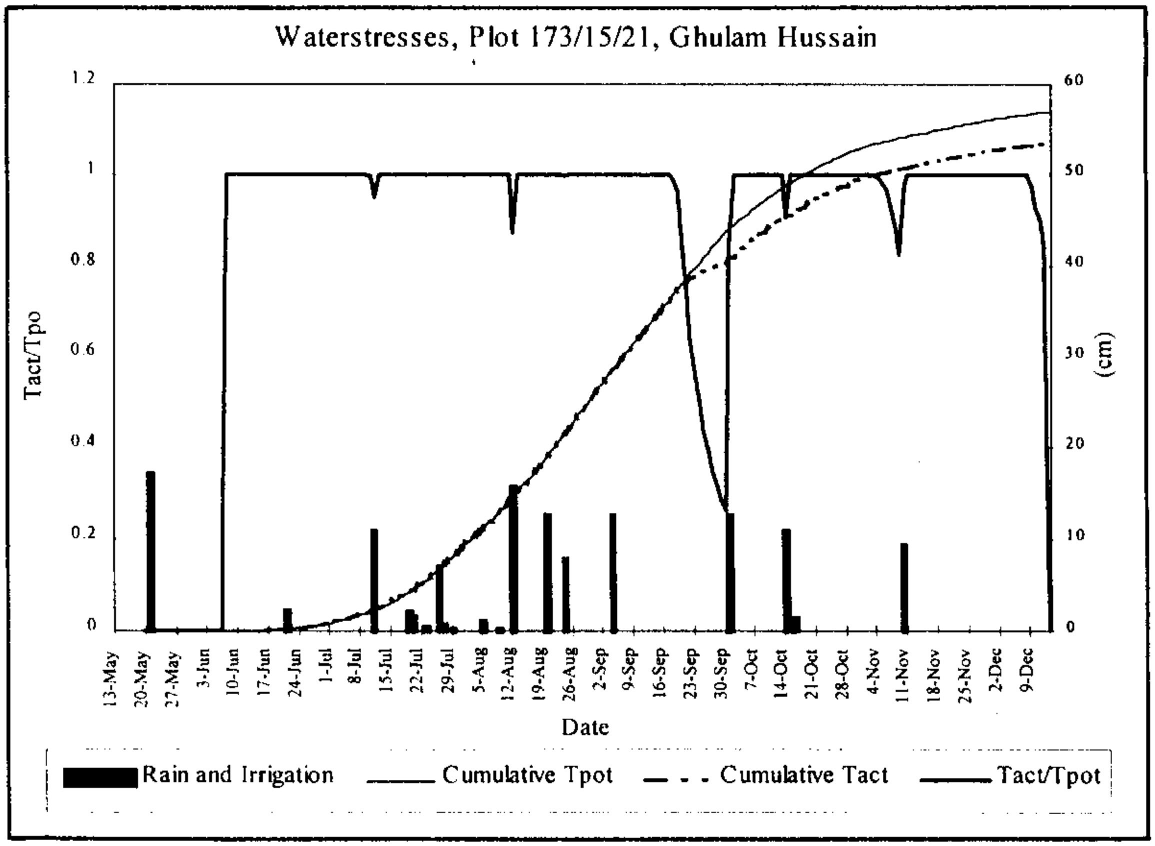

Figure 5.2. Waterstress for plot 173/15/21, Ghulam Hussain

- *Strategy related to intra-farm water allocation.*

Water allocation was researched for **Ghulam Hussain** and **Qazi Muh. Ali.**

As example the tubewell water allocation of Ghulam Hussain is displayed in Figure 5.3. and the rainfall in Figure 5.4. (*Note*: The timing and amount of the rain showers as displayed in Figure 5.3. is considered representative for similar graphs in this chapter. First warabandi is week 1, starting at April 15).

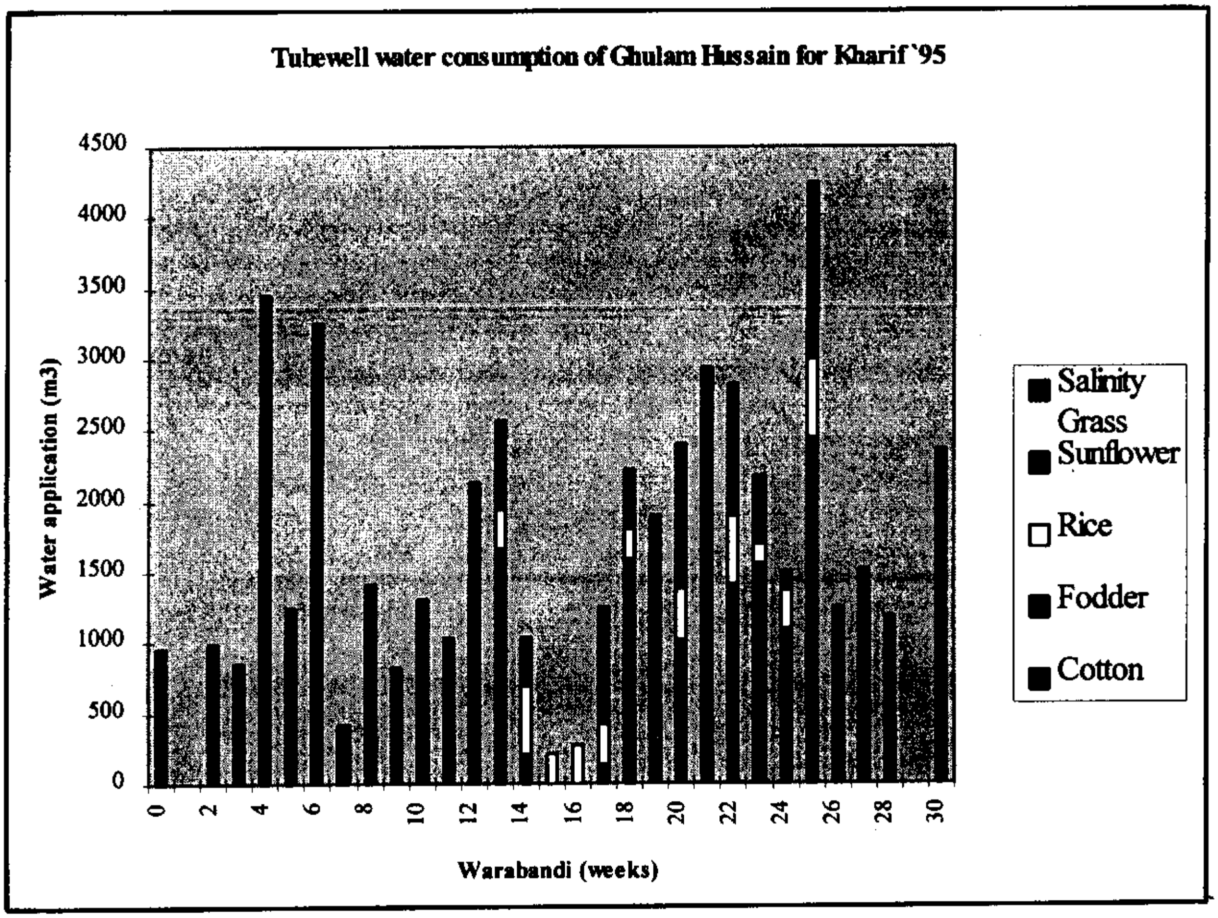

Figure 5.3. ***Tubewell water allocation for Ghulam Hussain***

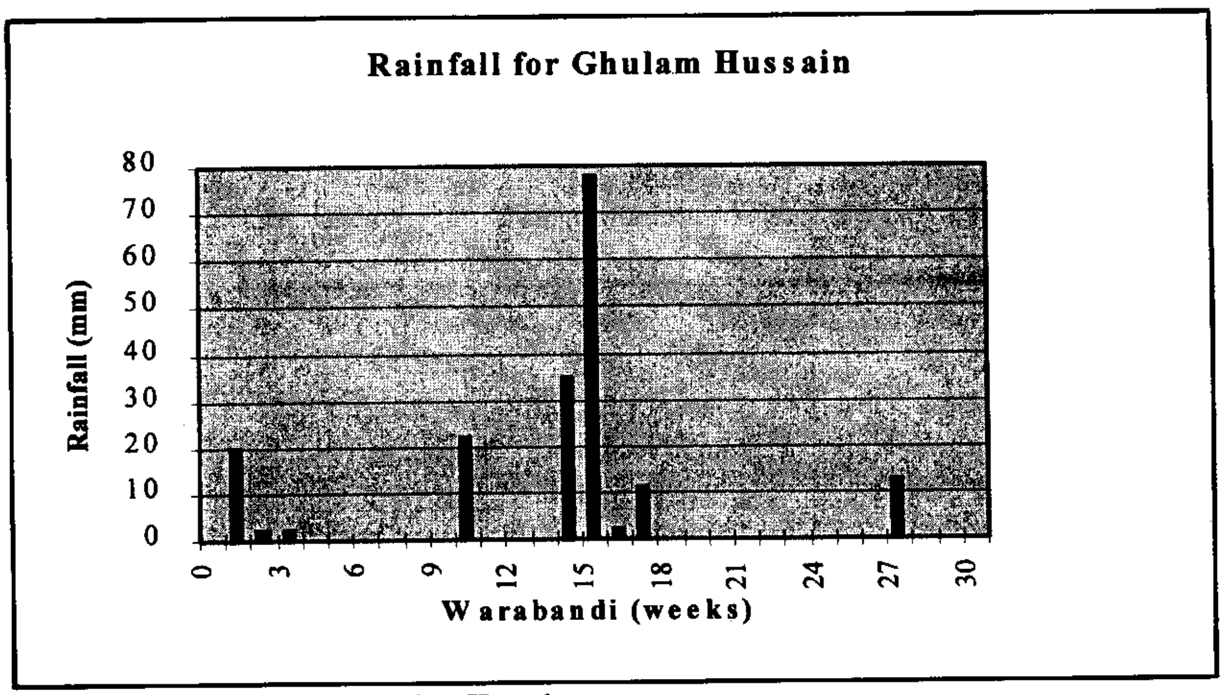

Figure 5.4. ***Rainfall for Ghulam Hussain***

Note: Timing and amount of showers to be considered representative for the rainfall in the area.

Water requirements are fully covered by tubewell water irrigation. Running the tubewell is not a problem for these farmers since their investment capacity is high. For both farmers also diversification in crops is not high. Cotton is sown by both of them, being the major cash crop at the farm and rice is sown on saline fields. The effect of rice cultivation is a leaching of the salts and therefore rice cultivation mitigates salinity. For Ghulam Hussain a major part of the total cultivated area is under salinity grass. Also here high water applications ensure a leaching of the salts.
None of the crops suffers from waterstresses. It even can be observed that considerable leachings are applied to cotton and rice, ranging from 250 to 500 mm. The leaching at the cotton plots is related to the salinity of the fields, more saline fields receive a higher leaching. It was shown in Chapter 3.4. that by high water applications the accumulation of salts decreased.
So by following a strategy of leaching, two objectives are served for this farmers:

1. Minimising the risk on waterstresses.
2. Mitigating salinity and reclaiming land.

From this strategy it is observed that:

- The possession of a tubewell and the availability of cash will ensure that the water requirements of crops is being covered for 100%.
- Mitigating salinity by leaching is possible in case of tubewell ownership and a large investment capacity.
- A large landholding will cause farmers to make their practices more homogenous.

5.3.2. Intensification by high tubewell and canal water consumption and high input consumption.

This strategy is followed by three farmers, Muh. Irshad, a Group 3 representatives, situated at Azim 20-L, Shakar Ali, a Group 2 representative and situated at Fordwah -14, and Muh. Islam, a group 11 representative situated at Fordwah 130.

- *Strategy related to farm characteristics.*

First the farms of Shakar Ali and Muh. Irshad will be discussed. Their main characteristics are:

- High ground water table.
- Quite good cash availability.
- Good labour availability.
- No machinery available, oxen are used (Irshad) or tractor is rented (Ali).
- Good canal water supply.
- Tubewell available.
- Market orientated.

The plots of Irshad are situated next to the Azim-distributary and Fordwah 14-R, where Shakar Ali is situated. is having a high water table due to seepage. According to field experiments of the Soil Survey Pakistan the ground water table is at 90 to 150 cm below the surface at this fields. For Irshad this is probably only the case at the time that the Azim distributary is operational, so during the Kharif. The benefit for the farmers is that a high percentage of the water requirements is covered by the capillary rise. So with low irrigation applications the crop water requirement is already covered.
The crop water requirement of cotton is mainly covered with tubewell water. Reasons for this are different for the two farmers.
Irshad is giving priority to sugarcane and rice, since these crops are the most water demanding and therefore would require a too high investment in tubewell water.

Besides this reason, the warabandi turn for Shakar Ali is short due to his small farm size, and so the choice is made to give the majority of the canal water to other crops with higher water requirements, so to rice and sugarcane. In this way he avoids water losses due to filling times of the field watercourses.
The fact that the investment capacity is not high is reflected in the way that fertilisers are being used. A high percentage of fertilisers is applied after flowering and so is serving mainly a restoring purpose. Spray is considered to be more important, more money is invested and the applications are clearly preventive, applied in the beginning of the season.
Since machinery is not there and the labour resources are there, it can be observed that manual labour forms an important input.

Table 5.5. Technical sequence Muh. Irshad 506/15/18

Seedbed Preparation	Rauni	Sowing	Irrigation	Manual Labour	Mechanical Labour	Fertiliser	Spray	Yield	SAR6
4x ploughing. 1x levelling	2 times, 93 mm total canal water.	May 3& CM-240	1 Irrigation before the rains. At flowering one irrigation each 15 days. 183 mm canal water, 216 mm tubewell water.	1 hoeing before the rains. 80 hr/ha total	1 hoeing before the rains. 2 hoeings after the rains. All by oxen. 72.2 hr/ha total	1 bag of Ammonium nitrate at vegetative stage. 2 bags of Urea during/after flowering.	First spray August 6. 5 sprays, in total 4000 ml	5 pickings; 1480 kg/ha	7-8

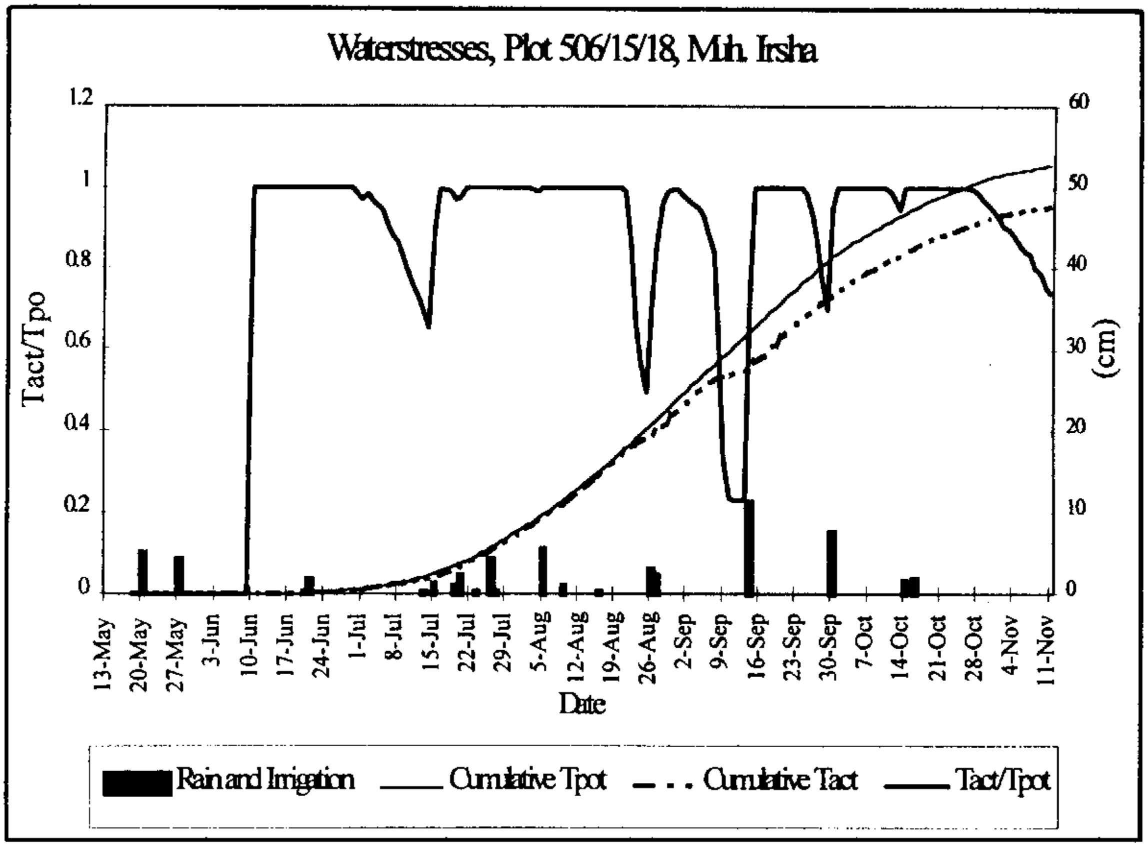

Figure 5.5. Waterstresses, Muh. Irshad, plot 506/15/18.

Muh. Islam is resembles Muh. Yaqoob, who follows the strategy of diversification, when the yield variability is concerned. Both farmers are situated at Fordwah -130 and face a high yield variability due to salinity and the absence of canal water at sowing time. The characteristics of Islam are.

- Large total operated area

- Large investment capacity
- Good farm assets, i.e. tubewell and tractor owner
- Good labour availability.
- High variability in soil fertility.
- Market orientated.

His main difference with Yaqoob, is his investment capacity and the labour constraint. Therefore his reaction to decreasing yields and increasing variability in yields is different. His low yield levels are compensated with high inputs and water applications and an increased use of machinery. Still this high application do not decrease the variability of the yield. One way of leaving his land fertile is by leaving 7% of his land fallow during Kharif. The labour constraint is expressed in the fact that clusters of fields get exactly the same treatment.
Diversification is practised within his irrigation practices. This is due to the large total cultivated area and the fact that his plots are more or less scattered over the watercourse. Therefore the possibilities to adapt the irrigation practices to the crop water requirements decrease.

From the strategy of Islam it can be observed that:
- Without good labour availability the strategy of diversification is difficult to follow.
- High input supply does not decrease yield variability.

- *Strategy related to intra-farm water allocation*

Water allocation has been researched for **Shakar Ali** and **Muh. Irshad**.

As example canal and tubewell allocation is displayed for Muh. Irshad in Figure 5.6.a. and b

- Canal water allocation.

For both farmers it can be observed that sugarcane, vegetables and fodder get priority in the beginning of the Kharif. Extra warabandi turns are obtained in order to irrigate them. Cotton receives less canal water and a major part of the rauni is performed with tubewell water.
At the time of the rainy season the priority is shifting to rice, which is sown at the end of the rainy season. A lot of water is needed for the seedbed preparation.
After the rains most of the canal water is allocated to vegetables, sugarcane and rice.
It can be observed that towards the end of the season some warabandi turns are refunded, probably for the turns obtained at the beginning of the Kharif.
For Shakar Ali the hypothesis is that he sells more warabandi turns than he gains. Is overall canal water use is the lowest from all farmers, while at the same time he is situated at the head of the system.

- Tubewell water allocation.

Tubewell water is mainly used for the rauni of cotton and fodder and serving as an additional allocation to sugarcane, vegetables and rice After the rains tubewell water supplies the majority of water to cotton and fodder and at the time that warabandi turns are missed it supplies water to the other crops also.

Crops that are left without waterstress are cotton, sugarcane and vegetables. With them the farmers do not want to take any risk at all. For sugarcane and vegetables an over irrigation can be observed, especially in the case of Shakar Ali.
The fact that sugarcane and vegetables receive mostly canal water is because of their high salt sensitivity, as reported by the farmers.

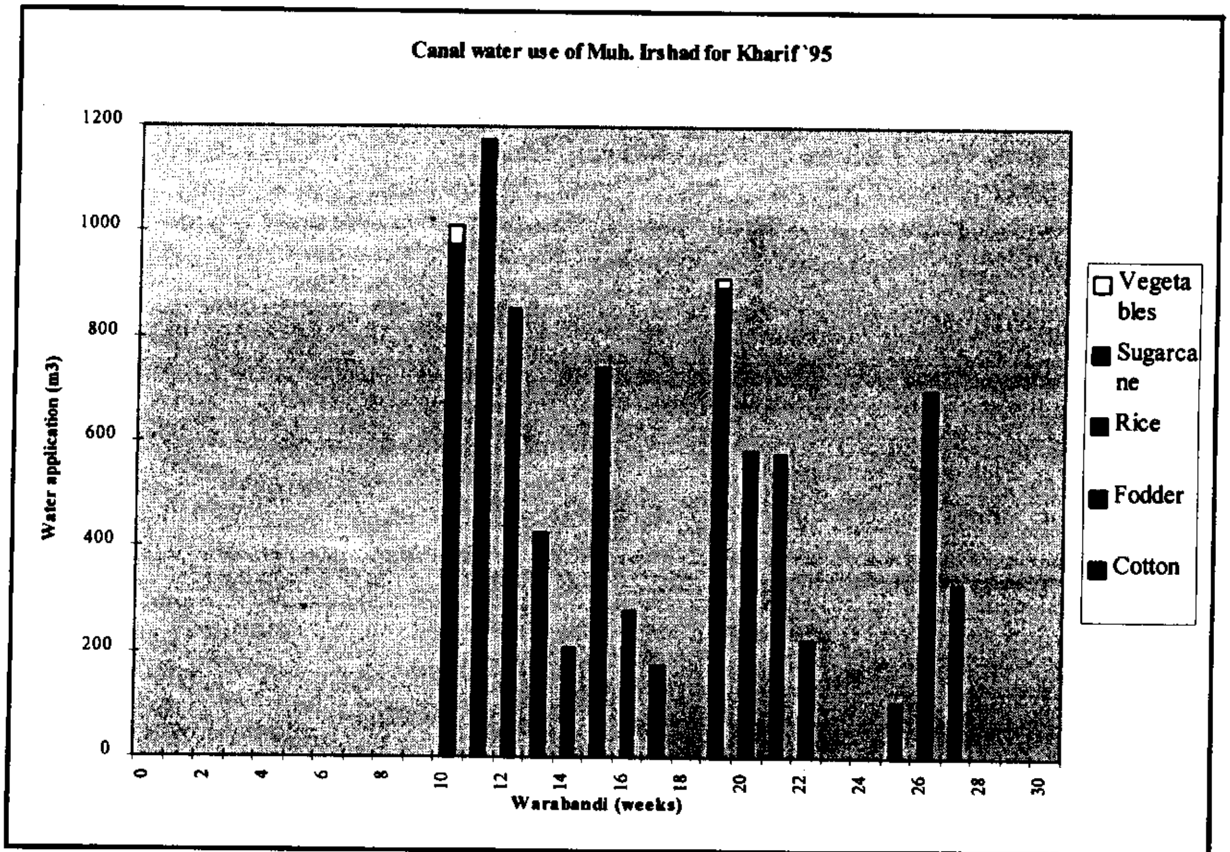

Figure 5.6.a. Canal water allocation of Muh. Irshad

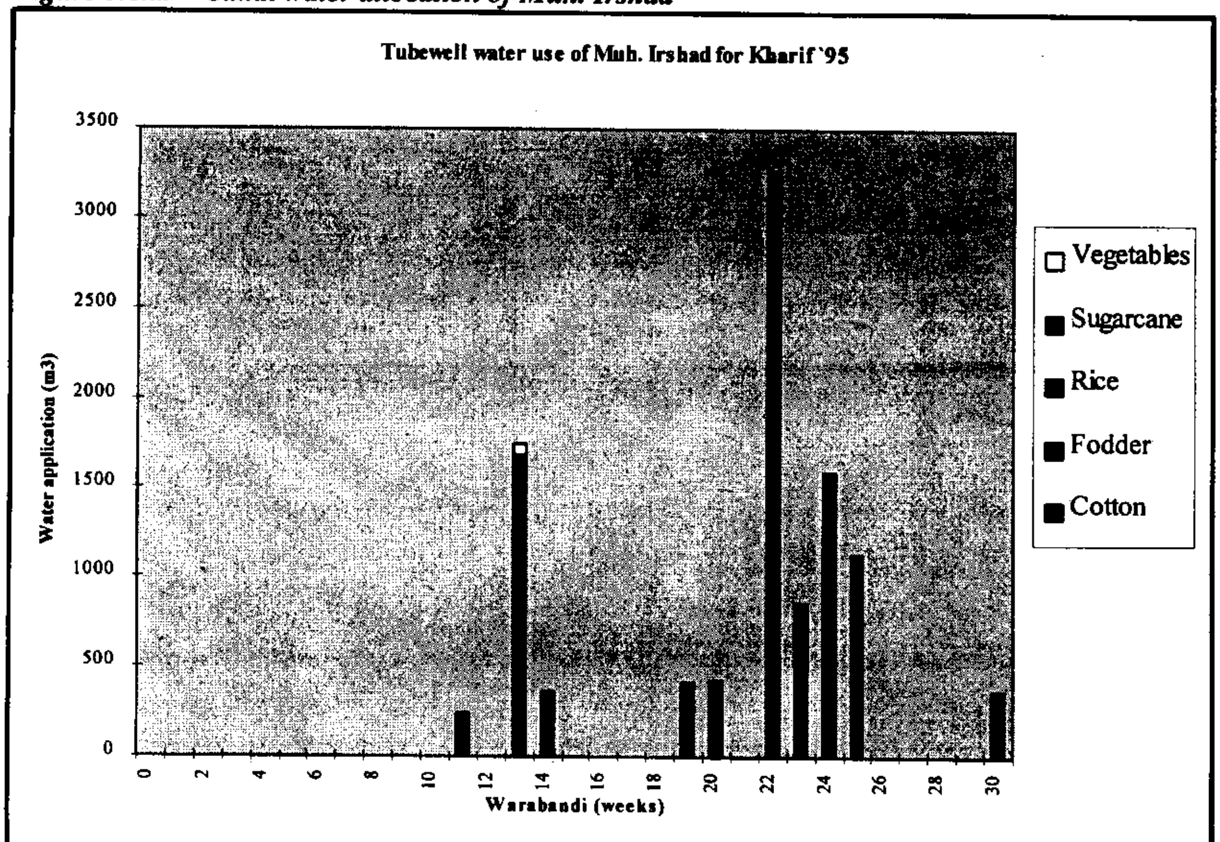

Figure 5.6.b. Tubewell water allocation of Muh. Irshad

5.3.3. Intensification with water application and low input applications.

This strategy is mainly used by Haji Elahi Baksh, a Group 9 representative situated at Fordwah 46-R, Bashir Ahmad, a Group 1 representative situated at Fordwah 62-R and Abdul Sattar 208, situated at Azim 111-L

- *Strategy related to farm characteristics.*

Their characteristics are:

- Large total operated area
- Quite low cash availability
- Good farm assets, i.e. tubewell and tractor owners
- Good labour availability.
- Market orientated.

The difference between Abdul Sattar 208 and Baksh and Ahmad, is the fact that Sattar is situated at Azim 111-L and therefore is only able to use tubewell water.
In fact this strategy is mainly determined by the cash availability constraint. Therefore it is not possible to intensify as much as they want to. The effect is that extra water is allocated to the cotton, in order to ensure that water is not the limiting factor. To increase the total farm income, some plots are also cultivated under long-term contracts. Since allocation of the inputs has to be done with care, it can be observed that inputs are applied in a restoring way.
Baksh is cultivating crops with a lower water requirement at the end of his farm, further away from the canal, so more waterstresses are allowed there. Also the plots with a good soil, which will obtain good yields any way, are only enriched with farm yard manure once in a while to ensure a long-term fertility and receive little inputs. The fertilisers are mainly supplied to the fields with less fertility. Spray is used the other way around. The best fields get sprayed early. This is done, because it is known that the effect of early spray is bigger than the effect of early fertiliser.
The strategy becomes especially clear when the water allocation and fertiliser application is considered in the case of Bashir Ahmad. After germination it appeared that germination on one field was better than on the other field, due to a difference in soil types. Instead of allocating more water on fertiliser to the good field, it was observed that the worse field had to be restored. In this way the farmer would take less risk in his investment, since according to him the impact of extra fertilisers would have a higher impact on the bad field.
Yields are ranging from low to high, which is mainly determined by the soil type and the spray use.

- *Strategy related to intra-farm water allocation*

Water allocation has been researched for **Haji Elahi Baksh.**

An example of the water allocation is displayed in Figure 5.7.a. and b.

- Canal water allocation

In the first period of the Kharif it is fodder which has the priority. At sowing time the priority shifts to cotton. For this irrigation probably an extra turn was obtained.
In the period before the rain cotton gets priority to apply the first irrigation after sowing. It is unclear why at this time also an application is given to a fallow plot. Water could have been available in excess and was applied for leaching or the farmer was planning to sow a plot and after irrigating decided to leave it fallow.
Canal water irrigation does not stop during the rainy period. In this time again water is supplied to a fallow plot, probably for the reason of having excess water which can be used to leach salts out.

After the rainy period most of the water is supplied to cotton, since this is the most sensitive stage for the cotton. At the end of the season is not done every week, so warabandi turns from other farmers that have been used in the beginning of the Kharif or that will be used in the beginning of the Rabi are refunded at this time.

Table 5.6. Technical sequence of Haji Elahi Baksh, plot 410/11/6

Seedbed Preparation	Rauni	Sowing	Irrigation	Manual Labour	Mechanical Labour	Fertiliser	Spray	Yield	SAR6
4x ploughing. 2x levelling	1 time, 108 mm total canal water	June 5 BH-36	1 Irrigation before the rains. At flowering one irrigation each 15 days. 725 mm canal water. 307 mm tubewell water.	1 hoeing before the rains. 2 hoeings after the rain. 165 hr/ha total	1 hoeing before the rains. 2 hoeings after the rains. 14 hr/ha total	1 bag of Urea, 1 bags of DAP during vegetative stage	First spray August 21. 3 sprays, in total 1290 ml	5 pickings; 365 kg/ha	7-8

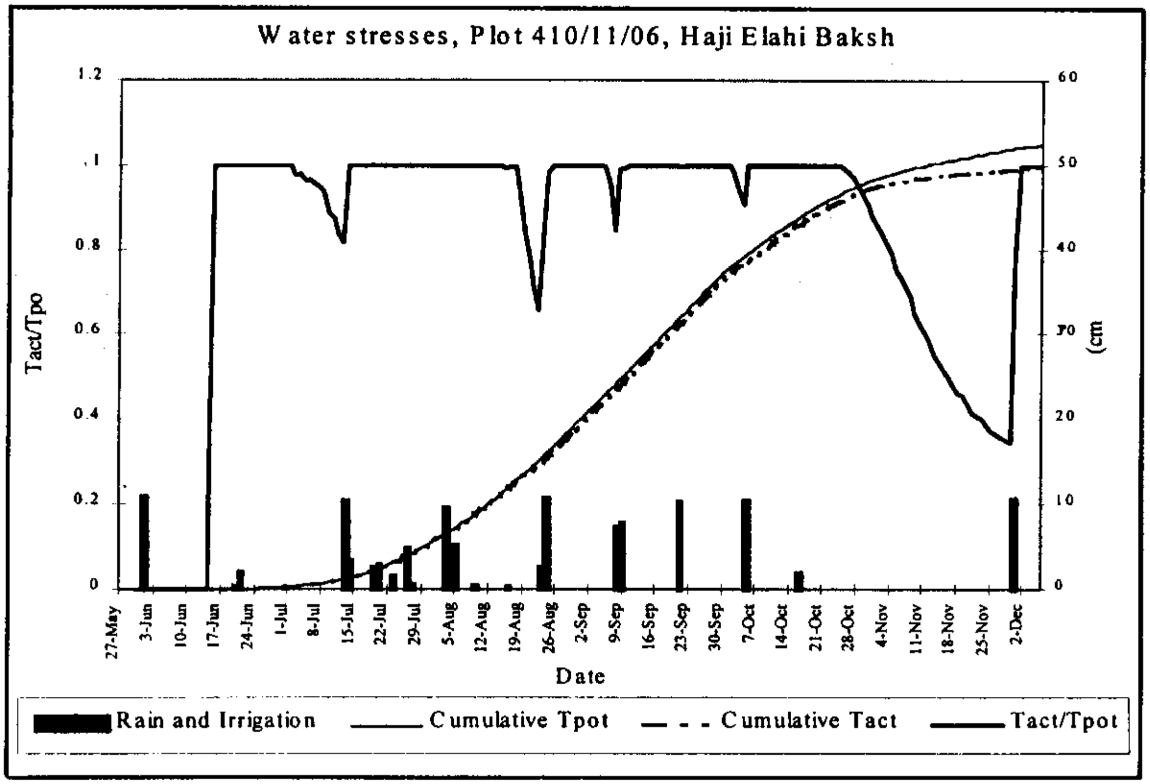

Figure 5.7. Waterstresses, Haji Elahi Baksh, plot 410/11/6

- Tubewell water allocation

Little additional irrigation for cotton and fodder is applied in the beginning of the Kharif. It is only after the rain, so at the period of early flowering that a high amount of tubewell water is applied in addition of the canal water, in the first place to cotton, but also a small quantity for fodder.
Later in Kharif tubewell applications take into account for a bigger part of the water requirement of cotton, especially when canal water is not used at all.
For cotton it can be observed that two groups of fields can be distinguished.
1. Fields at the north side of the farm, more sandy and further away from the nakkha and the tubewell.
2. Fields at the south side, loamy and closer to the nakkha and the tubewell.

The first group is sown one week after the second group. The main difference in water allocation is the higher irrigation frequency which is used for the fields of group 2, 8 versus 6. The extra applications consist of canal water.

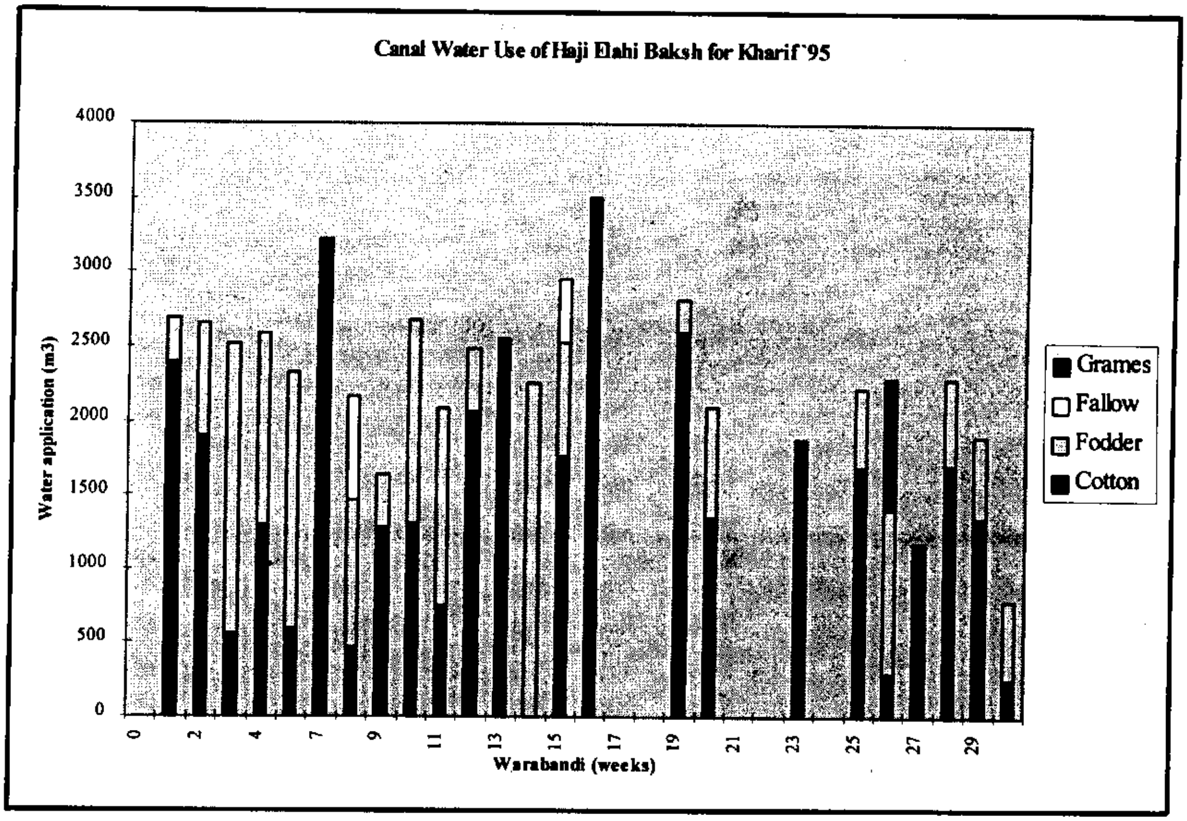

Figure 5.8.a. Canal water allocation of Haji Elahi Baksh

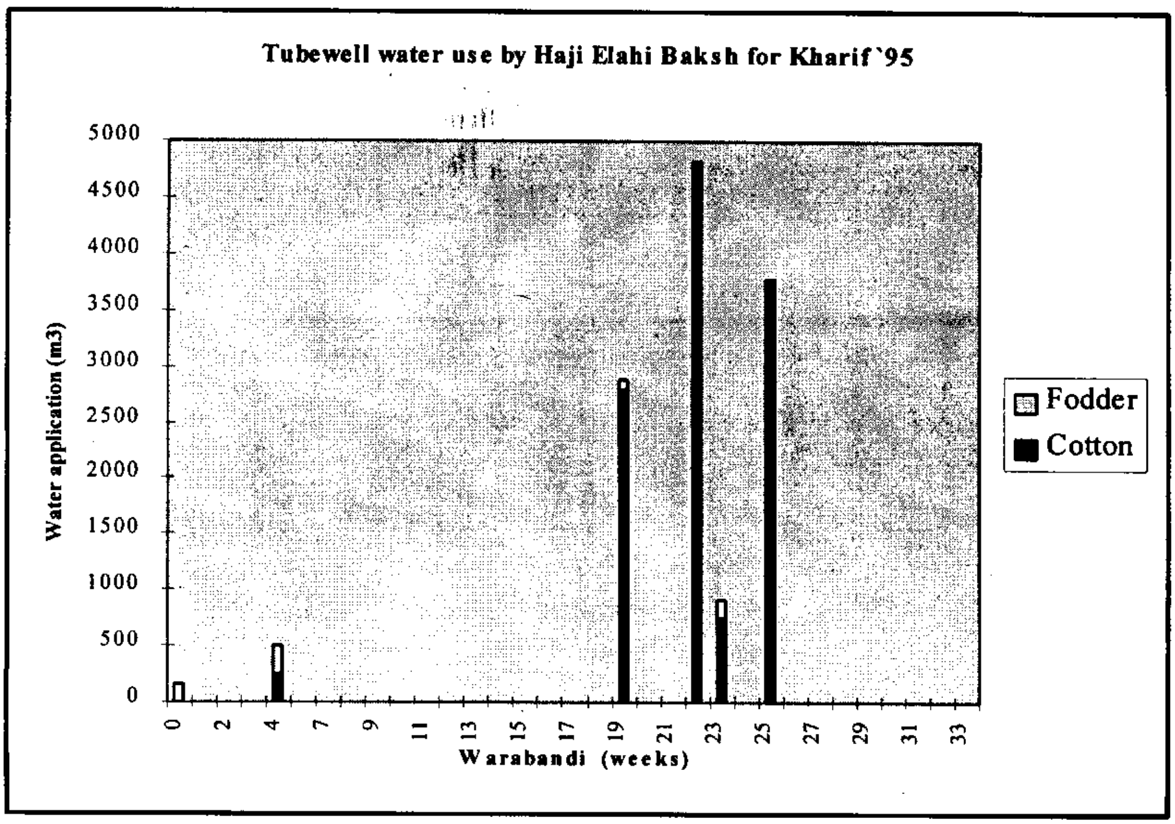

Figure 5.8.b. Tubewell water allocation of Haji Elahi Baksh

All the fields do not suffer considerable waterstresses. Main objective with cotton seems to keep the good fields free from salts, since more canal water is applied there.
All the fodder fields suffer from considerable waterstress in week 21 to 25. This is exactly in the time that the cotton fields get irrigated well in order to keep them free from waterstresses during the flowering.
So, cotton gets priority over fodder.

5.3.4. Diversification of water and inputs.

This strategy is mainly followed by one farmer, Muh. Yaqoob, situated at Fordwah 130-R.

- *Strategy related to farm characteristics*

His characteristics are:

- Large total operated area
- Large investment capacity
- Good farm assets, i.e. tubewell and tractor owner
- Good labour availability.
- Slight water constraint
- High variability in soil fertility.
- Market orientated.

On the farm salinity, water and the low cash availability are a constraint.
The effect of the salinity is that yields are decreasing slowly, according to the farmer.
Since Yaqoob does not have the long-term resources to keep increasing his input supply and since he notices that this strategy would not solve problems in the long-term he is diversifying his practices and varieties at his farm. The diversification is done within the cotton-wheat rotation, which stays the main rotation at the farm. It has two purposes, 1. The spreading of the risks and 2. To investigate different cropping patterns to see whether they are suitable for future use.
Experiments are done with the water requirements of different varieties. Yaqoob even decided to cultivate an important part of his total cultivated area under Desi-cotton, the local variety, which only finds its' use on the local market, for a slightly lower price than the high yielding varieties. This variety is said to extract less nutrients from the soil. Also on some fields fodder is intercropped with the cotton.
In order to spread risks the fertilisers are used in a restorative way. The plots with a good soil, which will obtain good yields any way, are only enriched with farm yard manure once in a while to ensure a long-term fertility and receive little inputs. This inputs are mainly supplied to the fields with less fertility.
Also water allocations seem to follow this rule of thumb, i.e. good yielding fields with good soils receive less water.

From this farmer it can be observed that:

- Due to sodicity yields decrease and yield variability increases.
- Also farmers with good investment capacity try to minimise risks when yields decrease.

Table 5.7.a. Technical sequence of early cotton, Muh. Yaqoob, Plot 76/11/17

Seedbed Preparation	Rauni	Sowing	Irrigation	Manual Labour	Mechanical Labour	Fertiliser	Spray	Yield	SAR6
2x ploughing.	1x 105 mm Canal water	May 7 Desi	1 Irrigation before the rains. At flowering one irrigation each 20 days. 232 mm canal water, 180 mm tubewell water.	1 small hoeing before the rains. 1 small hoeing after the rain. 18 hr/ha total	1 hoeing after the rains. 4.4 hr/ha total.	None.	First spray September 1. 2 sprays, in total 1500 ml	6 pickings; 1060 kg/ha	7-8

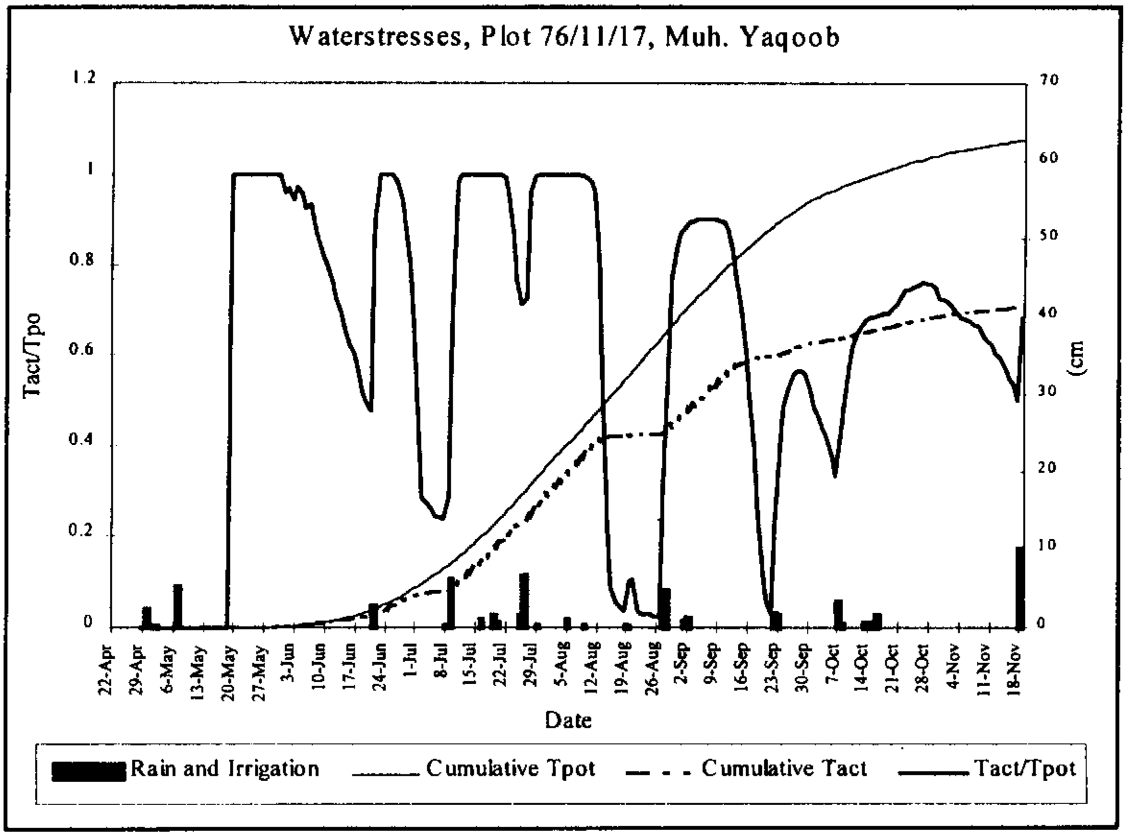

Figure 5.9.a. Waterstresses, Muh. Yaqoob, plot 76/11/17

Table 5.7.b. Technical sequence of medium cotton, Muh. Yaqoob, Plot 76/12/05

Seedbed Preparation	Rauni	Sowing	Irrigation	Manual Labour	Mechanical Labour	Fertiliser	Spray	Yield	SAR6
3x ploughing.	1x, 130 mm canal water, 46 mm tubewell water.	June 7 CM-240	1 Irrigation before the rains. At flowering one irrigation each 10 days. 298 mm canal water, 241 mm tubewell water	1 small hoeing before the rains. 1 small hoeing after the rain. 35 hr/ha total	1 hoeing before the rains. 3 small hoeings after the rains. 7.1 hr/ha total	1 bag of SSP at sowing. 1.5 bag of Nitrophos at early flowering. 1 bag of Urea at peak flowering.	First spray August 19. 3 sprays, in total 2625 ml.	4 pickings; 1180 kg/ha	7-8

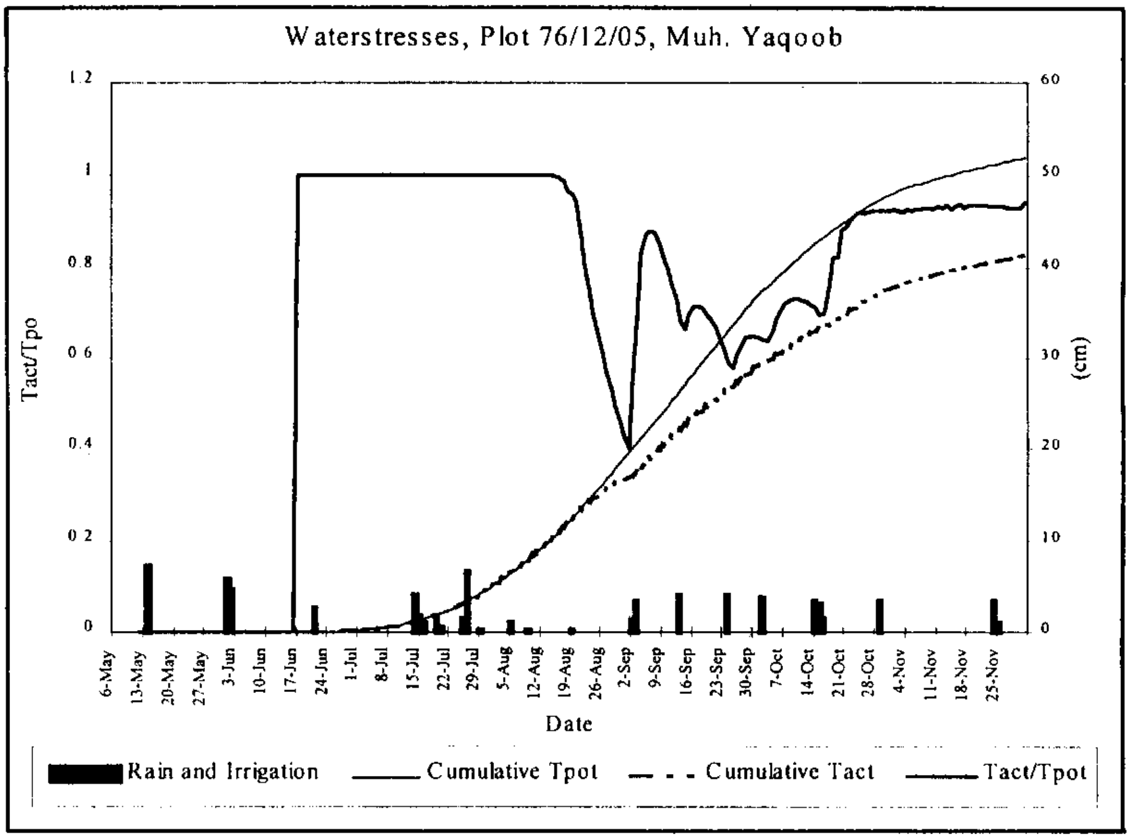

Figure 5.9.b. Waterstresses, Muh. Yaqoob, plot 76/12/05

Table 5.7.c. ***Technical sequence of late cotton, Muh. Yaqoob, Plot 76/16/01***

Seedbed Preparation	Rauni	Sowing	Irrigation	Manual Labour	Mechanical Labour	Fertiliser	Spray	Yield	SAR6
6x ploughing. 1x levelling	3 times, 105 mm canal water. 97 mm tubewell water.	June 26 CM-240	1 Irrigation before the rains. At flowering one irrigation each 13 days. 269 mm canal water, 264 mm tubewell water.	1 small hoeing before the rains. 2 hoeing after the rain. 98.2 hr/ha total.	2 weeding after the rains. 2.0 hr/ha total	1 bag of Nitrophos at squaring. 2 bags of Urea during flowering	First spray August 18. 5 sprays, in total 3125 ml	3 pickings; 480 kg/ha	7-8

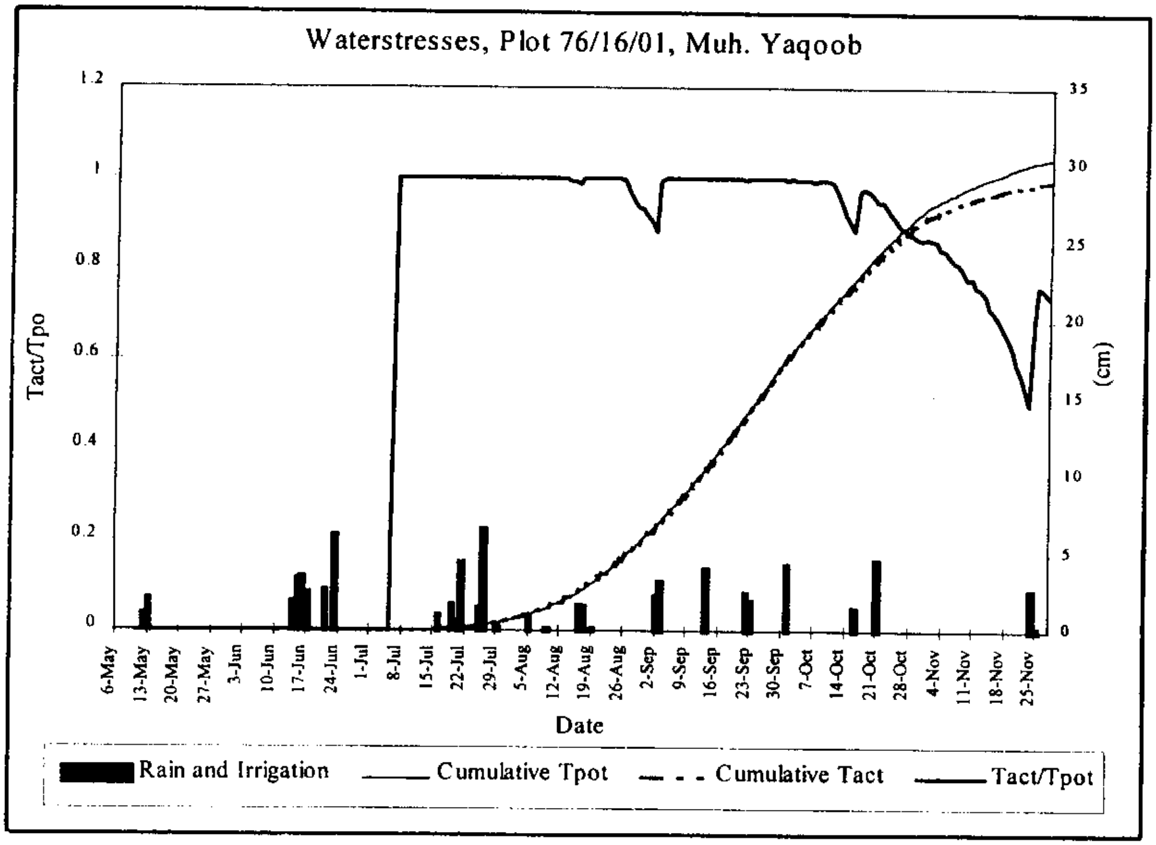

Figure 5.9.c. Waterstresses, Muh. Yaqoob, plot 76/16/01

- <u>Strategy related to intra-farm water allocation.</u>

Example of water allocation is displayed in Figure 5.10.a. and b.
Probably the farmer is willing to sacrifice some of his canal water for sowing the cotton, to keep the fodder and the sugarcane free from waterstress during this period.

- Canal water allocation

In the first weeks of the season priority is given to cotton, to perform the rauni for the early cotton, the Desi. Also water is supplied to fodder, some to sugarcane and the smallest part to vegetables. In week 3 and 4 extra warabandi turns are obtained to irrigate cotton.
Also in the period end May to mid June priority is given to the cotton-rauni, but less water is applied than in the weeks before. Also the quantity of one warabandi turn seems to decrease, probably due to illegal water extraction at the head end of the system. At this time also fodder and sugarcane are

irrigated. Extra warabandi turns are achieved in the weeks 11 and 12. In week 10 this turn is used to perform the rauni on the late sown cotton, in week 12 it is used to apply extra water to some fodder fields, which are sown at that time.
During the rains canal water is allocated to fodder only, and irrigation of cotton starts short after that. After the rains some extra warabandi hours are obtained to allocate water to the cotton. Fodder and sugarcane are almost not irrigated at this time with canal water.
During five weeks no warabandi turns are used. Probably refunding of the previous borrowed warabandi turns. At this time cotton stays the main priority to allocate canal water to.

Total water application is 6600 m3/ha, with 3950 m3/ha canal water and 2650 m3/ha tubewell water.

- Tubewell water.

The tubewell of Muh. Yaqoob has an EC of 1.42 dS/m, so the quality is bad.
Especially when sowing is in danger to be delayed, extra tubewell water is used in addition to the canal water rauni. Each week there is an irrigation until the rainy period, but applications are lower than the canal water applications. The main crops that are irrigated at this time are cotton and fodder. Also sugarcane and vegetables receive some water. During the rains irrigation stops. After the rains it can be observed that tubewell water is applied to cotton in the same amounts as canal water and that the water requirement of sugarcane is completely covered by tubewell water.
Irrigation by tubewell stops completely in week 27, when the pickings of the cotton start.
Cotton on average is using 3500 m3/ha of canal water, from which the majority is used at sowing time, and 2350 m3/ha of tubewell water. So with a crop water requirement of 700 mm and a rainfall of 250 mm it can be observed that the irrigation supply is close to the crop water requirement.
The water allocation to cotton can be distinguished in three groups according to their sowing dates:

1. Allocation to cotton sown at the beginning of May, the Desi.
2. Allocation to cotton sown at the beginning of June.
3. Allocation to cotton sown at the end of June.

1. With this cotton considerable waterstresses occur, but the variety is known to be resistant.
Only one rauni is applied and the first irrigation is applied with tubewell water 7 weeks after sowing. After the rain first canal and tubewell water is applied together, later on only tubewell water is applied. Severe waterstresses occur, since frequencies are too low and applications too small. Apparently the variety can resist it, since yields in this group are around 1000 kg/ha.
This sequence is mainly followed on sandy soils. It can also observed that this fields are located within two clusters which are the furthest away from the tubewell and the farm inlet.

2. This cotton is kept free from waterstress.
The cotton is sown by first applying tubewell water and afterwards leach salts from the top soil with canal water. After the rainy period irrigation is given with tubewell water and some weeks later this is shifting to canal water. This is probably done in order to ensure the crop is without waterstress in the most essential period, the early flowering. This sequence is mainly followed on loamy soils at a medium distance from the tubewell and the farm nakkha.

3. Water applications for this group are very variable.
In this case there is a tight relation between the water application and the germination of the crop; Some crops, even when sown late, did germinate well and received a lot of water. Other crops, with a worse germination, received less water. In some cases fodder was intercropped with this fields. In this group mainly the loamy fields with the best potential performance, close to the tubewell and the nakkha are represented. Apparently the farmer started sowing at his worst fields, the most far away from the nakkha and the tubewell and planned to finish close to the tubewell before the rains would come.

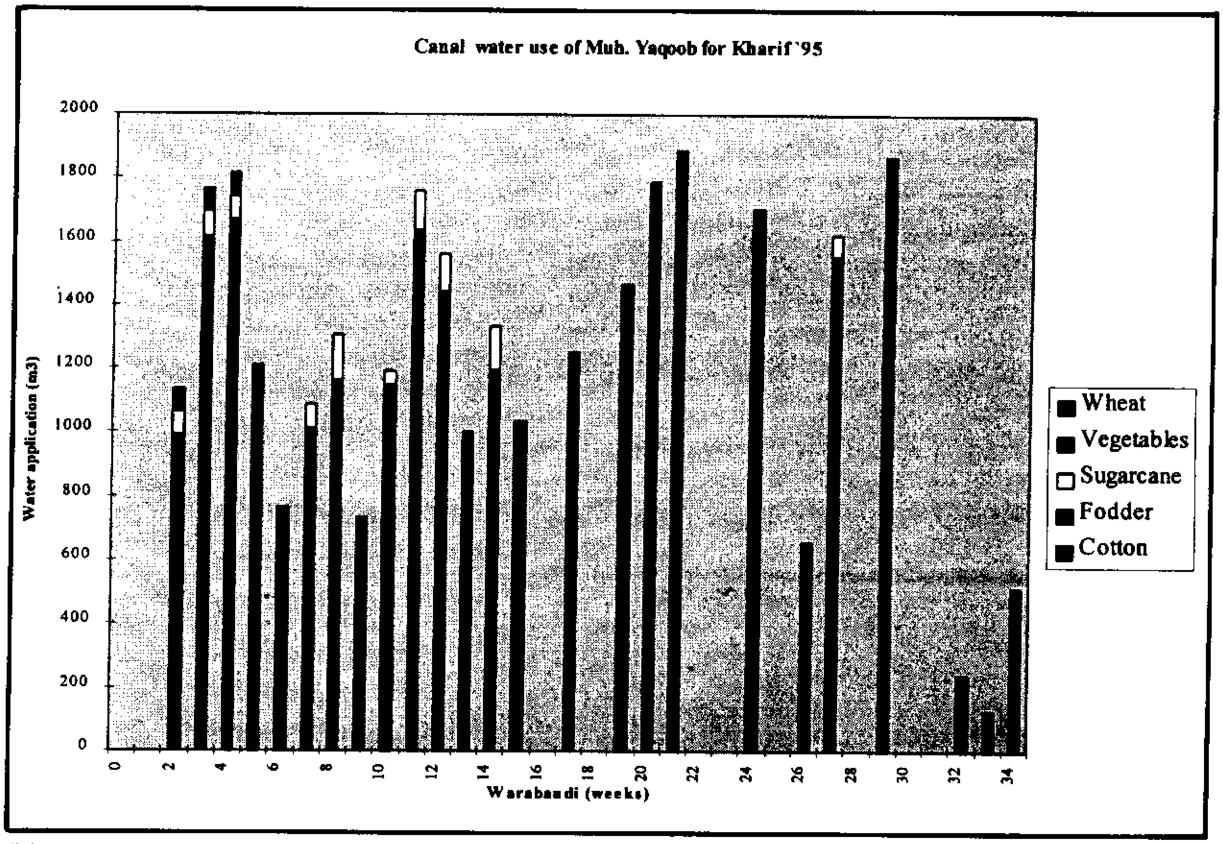

Figure 5.10.a. Canal water allocation of Muh. Yaqoob

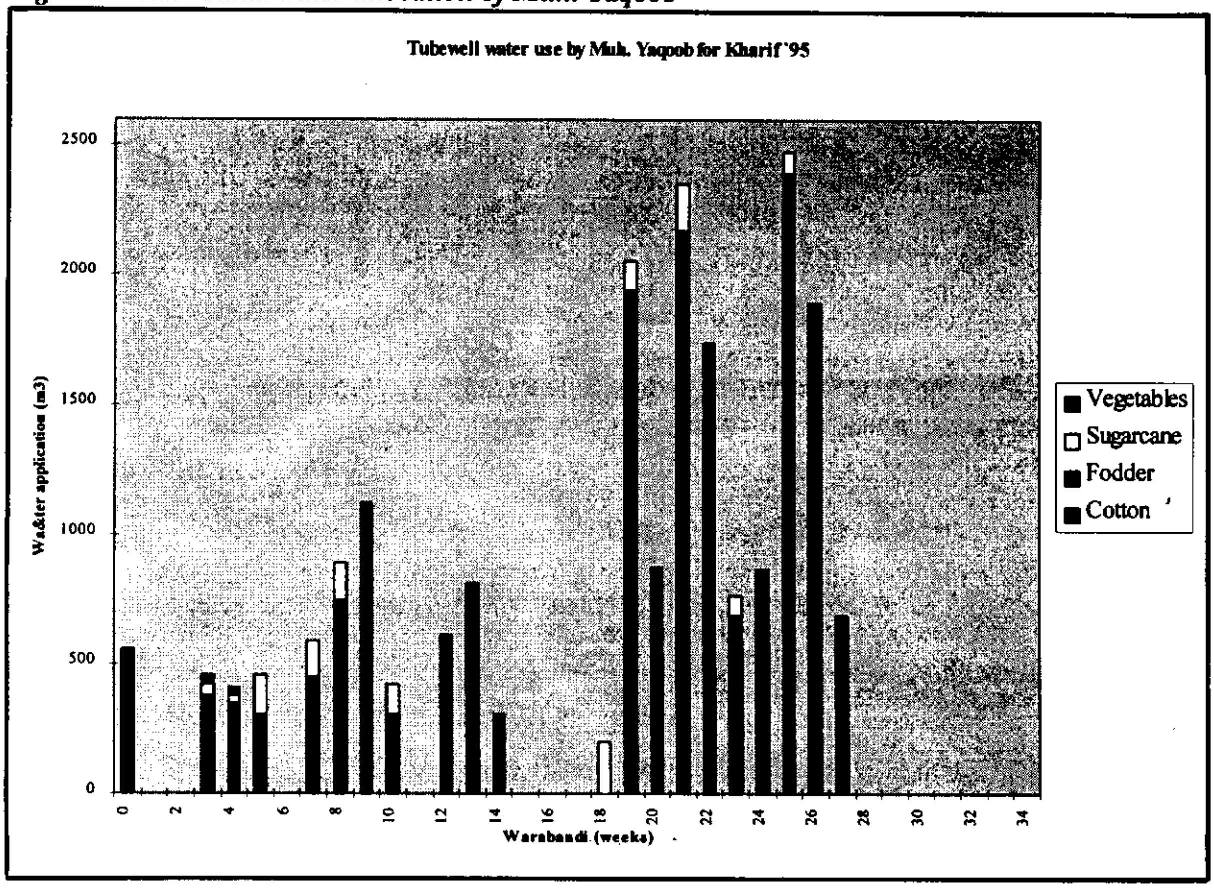

Figure 5.10.b. Tubewell water allocation of Muh. Yaqoob

The main objective is to ensure a certain yield level by favouring in sowing date the bad fields and afterwards supply good irrigation to fields with have germinated well and bad irrigation to the bad germinated fields.

Fodder

Fodder receives most of the canal water, 10500 m3/ha. Also tubewell water applications are the highest for fodder, 6000 m3/ha. The majority of this applications are done before the rains. Apparently the farmer does not want to take any risk for fodder, since the area under fodder is already small.

- Sugarcane

Sugarcane is receiving 3900 m3/ha of canal water and 5300 m3/ha of tubewell water. With a rainfall of 250 mm considered this seems enough. Also here the majority of the applications is applied before the rains.

5.3.5. Extensivation

This strategy is mainly followed by four farmers. Two are representative of Group 4 and situated at Fordwah 130-R, Abdul Sattar, I.D. 267. and Muh. Youssaf. For this group of farmers it is difficult to obtain good yields and profit. Their main objective is subsistence.
Within them a distinction can be made between the *extensification via tenancy* and the *extensification via ownership.*

- *Strategy related to farm characteristics*

- *Via tenancy*

Muh. Youssaf and Abdul Sattar 267 extensivate by renting in land.
Their main characteristics are:

- Low canal water availability
- Low investment capacity
- High percentage of rented land of the total cultivated area.
- Little farm assets, i.e. no tubewell or tractor.
- Saline and sodic properties, only for Youssaf and Sattar.

Due to the low investment capacity a moderate overall farm income is realised by renting in additional land, in the case of Muh. Youssaf from a landlord under share-cropping conditions, in the case of Abdul Sattar. Also at the cotton fields intercropping with fodder is done, since livestock is an important component within the overall objective. This is considered the most secure way, since intensification by increasing the inputs requires cash investments and therefor is more risky. Inputs are only applied at 2 out of 8 fields and are applied late, so they have a restoring purpose.
The low canal water availability at Fordwah 130-R, especially has its' impact at the time of sowing. Since sodicity is high at this watercourse it is very important to ensure a good germination by washing out all the salts with the rauni irrigations. Illegal extraction from the system at this time of the year is big and therefor being at the tail end of the system this farmers do not receive any canal water until the mid of June. Sowing dates are delayed by this, so germination is affected, in the case of Abdul Sattar severely.
The water requirements of the cotton have to be covered mostly by tubewell water. This is difficult to obtain, since a tubewell is no owned. The impact on the irrigation scheduling is that total water applications in general are low to normal, but the irrigation timing is not adequate and especially the irrigation frequency is too low.

The contract for renting in land is having big consequences for Muh, Youssaf. He is dependent form the land owner to obtain inputs and to obtain tubewell water. Also the owner obliges him to spent more labour hours on the share-cropped fields and to wait with irrigating his own fields after the share-cropped fields are irrigated.
The farmers are aware that salinity and sodicity is a big problem at their fields and that solutions for this are obtainable by for instance applying gypsum to their fields. Still it does not have any priorities in the practices. Yields are very low to low.
From this it can be observed that:

- Share-cropping contracts can have a big impact on farmers' practices.
- Sowing is delayed in the tail-end watercourses due to the absence of canal water.
- A low water availability because of low canal water availability and no own tubewell water availability combined with a low investment capacity leads to a inadequate irrigation sequence.
- Under cash constraint and an auto-consumption objective, the strategy that is followed tries to exclude any risk in the production, rather then to obtain high yields.

- *Via ownership*

This strategy is followed by two farmers at Fordwah 62-R, Barkat Ali and Muh. Siddique Haleem. Ali is a group 9 representative and Haleem is a group 1 representative. There is a difference in labour availability and investment capacity between the two of them, so their strategies are slightly different.
Their main characteristics are:

- A medium good canal water supply.
- A small total operated area.
- A medium (Ali) to low (Haleem) investment capacity.
- A low to labour availability.
- No tubewell, not owned (Haleem) or broken (Ali) at period of high water requirement.

Since the investment capacity is low, tubewell water could only be purchased and the total cultivated area is small the only way for the farmers to obtain a proper income from cotton is by intensification by means of canal water and manual labour. Especially for Haleem this is surprising since his labour availability is under pressure due to the fact he also is a teacher besides a farmer. The money earned by teaching is mainly invested in -non-agricultural activities. The low investment capacity stresses the input applications. For Ali the spray and fertiliser applications are medium, for Haleem this applications are low.
Barkat Ali also owns a tractor and still does not use it often, because of the fuel requirements. Also for this farmer a restriction in investment capacity shows itself in the way that water and inputs are used. One of the fields was damaged due to waterstress caused by the break down of the tubewell. It was decided then to apply the majority of the canal water to another field, with a better crop condition. Once the tubewell was installed again, Ali decided to apply extra tubewell water and fertiliser to the worse field, in order to restore the crop.
Still yield levels are low for both farmers. This is mainly due to an inadequate irrigation. The total water applications are similar to the farmers who follow the strategy of intensification by high tubewell water applications and manual labour, but the irrigation frequencies are lower. An extra yield decreasing effect is caused by the worse soils.

- <u>*Strategy related to intra-farm water allocation.*</u>

Water allocation has been researched for **Abdul Sattar 267**.

An example of the water allocation is displayed in Figure 5.12.a. and b.

• Canal water

Canal water is the main water source. Irrigation is done every week. The crops to which water is allocated are cotton and fodder. Over the whole growing season it can be observed that cotton is receiving more water than the fodder.

During the rains again extra water is received by the farmer. This water is applied to a fallow field in order to leach the salts away.

Table 5.8. Technical sequence of late cotton, Muh. Youssaf, Plot 97/02/07.

Seedbed Preparation	Rauni	Sowing	Irrigation	Manual Labour	Mechanical Labour	Fertiliser	Spray	Yield	SAR6
6x ploughing. 1x levelling	2 times, 59 mm canal water. 67 mm rented tubewell water.	June 14 MNH-109	2 Irrigation before the rains. At flowering one irrigation each 15 days. 394 mm canal water, 222 mm rented tubewell water.	2 hoeings after the rain. 56 hr/ha total.	1 weeding after the rains. 1.7 hr/ha total	0.5 bags of Urea during flowering	First spray August 23. 2 sprays, in total 1200 ml	4 pickings; 475 kg/ha	7-8

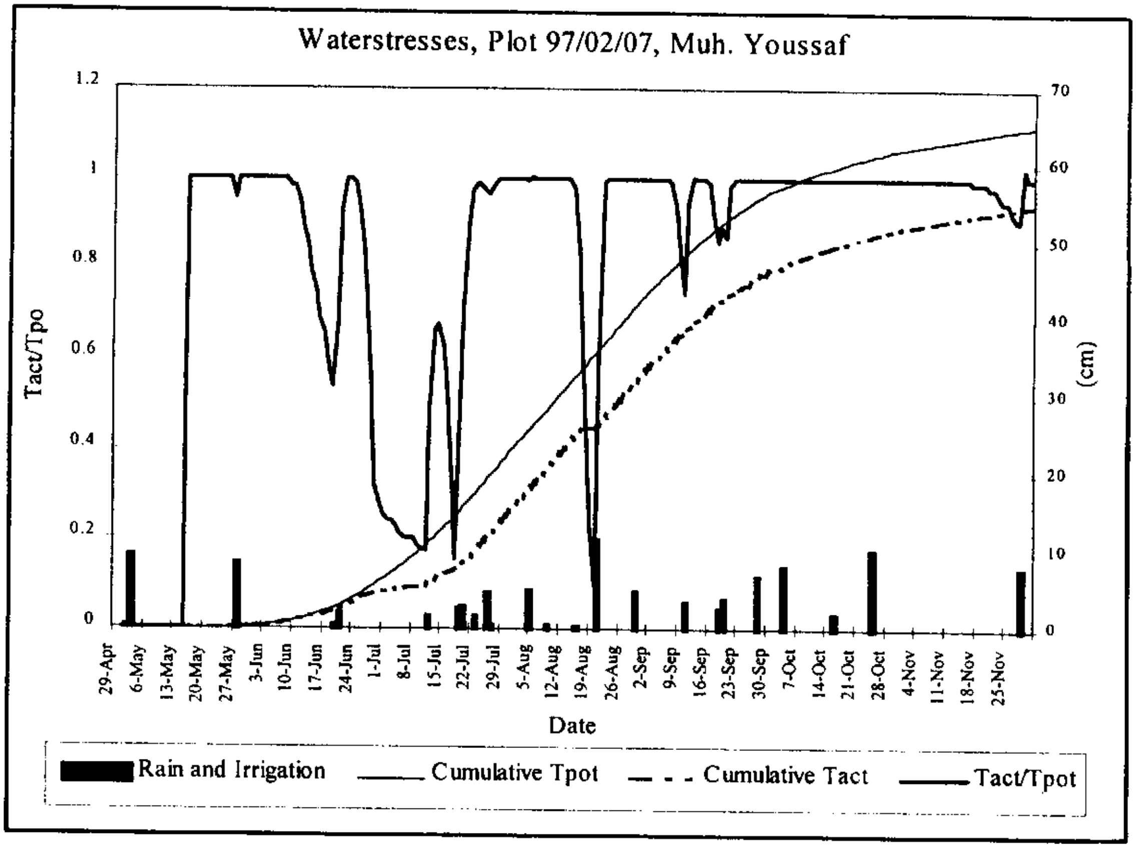

Figure 5.11. Waterstresses, Muh. Youssaf, plot 97/02/07

At the end of the season some warabandi turns are missed, but it does not look like he is using this water at another time, so probably the canal water was not available at that time.

• Tubewell water

Some tubewell water is used in the beginning of the Kharif to enhance the sowing of cotton and also right after the end of the rainy period, so at the early flowering stage of the cotton water is allocated to the cotton mainly.

Total farm water consumption is 3620 m3/ha, 3260 m3/ha canal water plus 360 m3/ha tubewell water

Cotton receives the majority of the canal water, 4700 m3/ha, will tubewell applications are very little, 620 m3/ha. The total applications are little and though the frequency of irrigating is high, the waterstresses are considerable. Waterstresses especially occur during the peak flowering and the bolls maturation.

- Fodder

With 1750 m3/ha of canal water and 300 m3/ha of tubewell water tubewell receives very little water and seems to be less important than cotton.

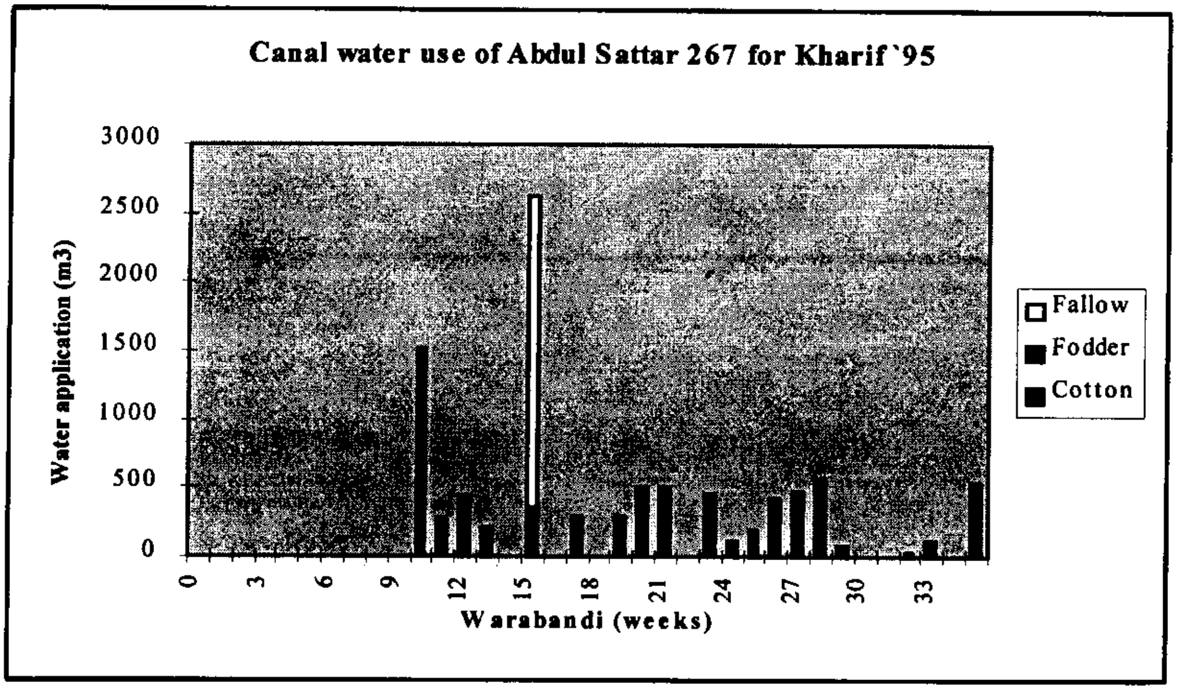

Figure 5.12.a. Canal water allocation of Abdul Sattar 267

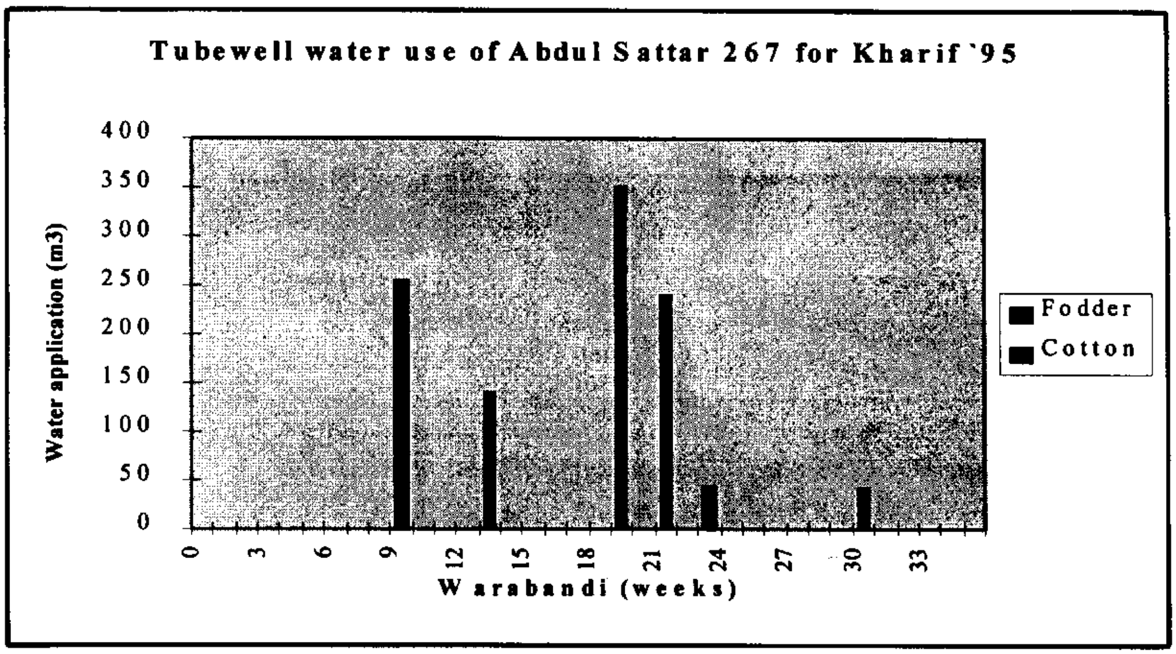

Figure 5.12.b. Tubewell water allocation of Abdul Sattar 267

CHAPTER 6 CONCLUSIONS

Methodology:

This study started to examine the practices of farmers at the field level and linked this to the global farm objective and the allocation of water. In this way it was possible to explain the cotton yields as a function of practices and to explain the practices as a function of overall farm strategies. So, a clear picture was obtained of farmers objectives and decision making processes.
The agronomic analysis succeeded in revealing the important factors that were influencing the yield. This was shown by means of the production function. The factors that appeared to be significant were already expected after the agronomic insight was established. An important tool for this analysis is the restitution of the results to the farmers. In this restitution the validity of the analysis is revealed.
For the research on the intra-farm water allocation the data were not sufficient to establish a thorough insight in the decision processes of farmers. The allocation of resources to crops is strongly interrelated and the plots that are allocated are the major resource. Vital information about plot characteristics was missing. Therefore, more research on this topic is needed.
CROPWAT was a sufficient tool to make a first inventory of water allocation. Only for specific situations, i.e. high ground water tables. it is less suitable.
Farm characteristics change, but despite this the typology that was used to relate the cotton practices to the farm characteristics proved to be useful. Only minor problems in the analysis occurred due to the fact that farms had changed.

Agronomic analysis and the production function.

The main factors that influenced cotton yields were inventoried. Nine groups of factors having their impact were distinguished:

1. *Cotton variety and seed quality*
2. *Soils*
3. *Seedbed preparation*
4. *Soil tillage after emergence and plant establishment*
5. *Fertiliser application*
6. *Diseases and spray use*
7. *Irrigation*
8. *Organic matter*
9. *Salinity and sodicity.*

- The major cotton *variety* used is a determinate cotton variety, CM-240. It is preferred because the performance is known. Therefore yield security is higher. The high water and input applications which are needed for this variety are of less importance for the farmers than the known performance. Also local cotton is popular. Its' yield is low, but the resistance against viruses and the low input and water applications that are needed make it popular. The indeterminate varieties are popular in case a good virus protection and input level can be assured. The highest yields were achieved with indeterminate varieties. The main complaint with this varieties is that the yield level is not very secure. This factor did not show in the production function. Probably farmers allocate good seeds to good plots together with other resources. In that way collinearities occurred.
- *Soils* are of great importance for achieving high cotton yields. Farmers often point to soil as an explanation for obtained yields. Variability of different soils with different qualities within the farms is high. Farmers in general allocate good soils together with high amounts of water and

fertiliser, in order to obtain peak yields, but in a few cases farmers levelled the yields by allocating water and inputs to worse soils. So also here collinearities occurred.

- *Seedbed preparation* is an important factor to ensure a good germination. A common sequence of activities is done on all the fields. The variability at this stage is mostly in the number of one practice that is carried out and not in the sequence. This variability is independent from the kind of power, animal power or machinery, that is used. One cotton variety, the local cotton, was receiving a different seedbed preparation, in a way that the amount of practices was reduced in order to save time and enable early sowing. Variability in sowing date proved to be because of labour constraints, lack of canal water, especially at the downstream watercourses, bad germination, the lack of equipment and the early rains that destroyed the crops. Especially at downstream watercourses were the canal water still reaches the sowing dates are delayed because of the highly variable water availability. The importance of a good seedbed preparation and early sowing was illustrated by the relation between the density of the soil cover, related to the germination, and the final yield that was obtained
- The *soil tillage after the germination* is variable both in nature and number of practices. Furrows are reported to be a common practice in the region, but this practice is mostly combined with hoeing activities, so notations of it were scarcely available. Thinning is hardly done by farmers. This is not because the necessity of the practices is unknown, but because the plant density on the field does not justify the costs of the practice. Hoeings are done both by tractors or oxen and by hand. All the farmers performed this practices, but their quality was difficult to judge, since no observations were done. The practices of ripping the subsoil, a deep cultivation, is not widely spread on the region. Only one farmer was met who was aware of the necessity of the practice. One farmer was met were the absence of this practice had lead to hard-pan formation. Also labour was not represented in the production function due to collineraties.
- Only two types of *fertilisers* are applied by the farmers, nitrogen and phosphate fertiliser. Mostly nitrogen fertilisers are applied. Phosphate is applied to a lesser extent and the use of potassium fertilisers was not met at all. The fertilisers are applied by most farmers with precaution. First they want to be sure that the crop installation is right and only afterwards they are willing to invest money in it. therefore only a very small percentage proved to be applied at the time of sowing.
- The production function showed the necessity of an early *spray* right after the first virus attack. In reality farmers delayed spraying since it was hoped that the virus attack would not be severe. Once it became clear that the attack was severe farmers started spraying. Only few farmers reacted immediately to the virus attack. Spray use was the most expensive input for the majority of the farmers. Since the problem of virus is occurring, the interest in the local cotton varieties and the virus resistant varieties like CM-240 is increasing.
- Average *water applications* in the area are higher than the recommended quantities. One reason for this is that most farmers want to exclude any risk for waterstress at the time that water is available, and after a period that waterstresses occurred an attempt is made to restore the crop. Another reason for this is that a few farmers at downstream watercourses in the possession of a tubewell use large quantities of water in order to mitigate salinity and secure the yields. In accordance with Malik et al. it was found in the statistical analysis that the period of early flowering was the most sensitive for waterstresses.
- *Soil organic matter contents* appeared to be very low to low. To obtain higher organic matter contents large quantities of farm yard manure are necessary, which can not be achieved by farmers. The low organic matter contents are related to the sodicity of the soil and so management of this factor becomes even more complicated. Within the statistical analysis farm yard manure applications were only within 10%-significance, but still the production function showed that manure application is having positive effects on yields.

- *Salinity and sodicity* proved to be a factor of major importance in cotton cultivation. Within the statistical analysis it appeared that the sodicity of the topsoil was having impact. Especially at the time of sowing farmers try to remove salts from the topsoil in order to ensure good germination. Still, to combat sodicity not only leaching of the salts is sufficient, since sodium will not be completely removed from the adsorption complex. Gypsum was not applied at the sample fields. Farmers are aware of the benefits of this amendment, but due to institutional constraints Gypsum is not available. Still, solid knowledge about the way that Gypsum should be applied was not met in the area, so in case of distribution of this amendment in the area, also knowledge should be provided in order to avoid hard-pan formation due the illuviation of sodium in a lower soil layer. Related to salinity and sodicity is the use of low-pH fertilisers. Out of experience farmers know that DAP and Urea, having a high pH, are hazardous on sodic soils. Still the use of this fertilisers is stimulated by the fertiliser suppliers, This is done by selling packages of fertiliser, which include DAP and Urea.
- *Yields* obtained in the region were higher than the average production achieved in Pakistan 1991. Reasons for this are not clear. Farmers try to maximise cotton yield by leaving the crop on the field up to one month after the recommended harvesting date. Another reason for the delay of harvesting is the labour constraint. The work is traditionally done by women, who take advantage of this position by delaying harvest in order to enlarge their income.

Restitution

- A common knowledge-constraint among farmers can not be identified. Farmers are in general well aware of their situation, there problems, and alternative strategies to deal with them. This knowledge is mostly obtained through own experience and by observing other farmers practices. If confronted with "paper"-knowledge, the reaction is sceptic, since the problem and the solution described is yet unknown. But most of the time the reason why the knowledge of a farmer does not come into practice are the constraints which are faced outside the farm, i.e. bad inputs supply due to low institutional performance, bad canal water supply, or inside the farm, i.e. low cash or labour availability.
- For this reason a restitution done by IIMI in this way is having little to no positive effect on the agricultural production of the farmers involved. IIMI can provide knowledge, but can not clear constraints.
- It is clear that farmers rely most of all on the experience of other farmers. IIMI therefor could be a intermediate between farmers who face the same problems and constraints but find different solutions for this. The advantage of IIMI is that they can compare the problems from different farmers at different watercourses, who would never meet each other because of distance. The disadvantage of IIMI is that the main objective is to formulate recommendations through research. Bringing farmers together in this way would require an active involvement in farmers' communities. The main profit could be a dissemination of the results among farmers themselves and a better contact between IIMI and the farmers' communities.

Statistical analysis

The final component of the agronomic analysis was a production function. In the statistical analysis six factors having impact were identified, five factors were used to create the production function. The production function is highly significant since a R-square of 0.87 was achieved.
One factor that can be developed further is the application of farm yard manure. Data on this subjected were collected at a time that farmers had difficulty to recall the amount and timing of applications. In the statistical analysis this factor appeared to have profound impact on cotton yields, but was not within the 5%-limit that was used for the production function. so if data quality on this factor is increased probably a higher significance can be established. When using this factor it should

be recalled that farm yard manure is having its' major impact two growing seasons after application.

Farmers strategies

No farmers are using canal water only. Even farmers with a high canal water availability used tubewell water in their cotton cultivation. Tubewell water use minimises the risk for waterstress and the effect of salinity is not affecting the cotton yield directly since cotton is less susceptible for salinity in later crop stages. The rauni irrigation however was always partly done with canal water in case canal water was available. This is done since cotton is sensitive to salinity at germination and therefore salts are leached from the topsoil

In case of *intensification by tubewell water and high inputs application* it was observed that this strategy was only followed at the downstream watercourse were no canal water was available and only by well equipped farmers with a large total operated area and good cash availability. Yields are good, despite the saline soils, since farmers compensate this by high water and input applications. Waterstresses did not occur here. For this group it is expected that Gypsum would be applied in high quantities if it would be available, since sodicity is the main constraint.

In case of *intensification by high tubewell and canal water consumption and high inputs application* it was observed that because of small canal water quantities per warabandi turn and the fact that sugarcane and vegetables are more salt sensitive than cotton, the cotton was mainly irrigated by means of tubewell water. This was made possible by the high groundwater levels which supplied water at the cotton. High water applications were used to keep the other crops from stresses.

In case of *intensification with water and low input applications* it was observed that this strategy is mainly due to a lower cash availability which does not allow intensification on the input side. Since water is the main resource it is managed very carefully, even though farm sizes are considerable. Different groups of fields with different allocations can be distinguished.

In case of *diversification of water and inputs* is was observed that this strategy was mainly because of variability of soil fertility. Therefore input and water supply becomes highly variable, in order to maximise profit, not yield.

Extensification was practised in case intensification was not possible due to cash constraints. It was done either via tenancy or via ownership. Tubewell water is used very little, since it is too expensive and tubewell is mostly not owned.

Recommendations for future research

- A major constraint for farmers, beside water, is the availability of fertilisers, sprays and equipment. This can be considered an institutional constraint. In order to get a good picture of farm management, research in this direction is necessary. This kind of research is relevant for an organisation as IIMI, since the allocation of resources, both water and other inputs, is highly interrelated.
- As observed with the cotton harvest farmers decisions also depends on family members. Therefore in the research on farmers behaviour the focus should be extended from the farmer himself to the whole farming system.
- In order to achieve good understanding about farmers decision processes regarding intra-farm water allocation, better than is achieved in this study, the following research should be done:

1. An inventory of crop characteristics in terms of water requirement, input requirement, soil requirements, salt sensitivity, and revenues.
2. An inventory of the characteristics of plots within a farm in terms of location, fertility, salinity and sodicity, water storage capacity and infiltration characteristics.
Knowing this both crop and plot characteristics an analysis of farm water management can be carried out. In this analysis not only the allocation of water should be considered, but also the allocation of other inputs.

- More research is needed on field irrigation practices. At this point water use efficiency is not high and too large quantities of water are applied and leached away.
- Since Zinc might become scarce for the plants in anaerobic conditions and this conditions can occur in case of sodicity due to swell and shrink, research is needed on this topic to gain more insight.
- In case of implementation of new agricultural techniques in the area of study, first an inventory of communication lines among farmers should be made. Once the risk-takers can be identified the dissemination of knowledge will find it fastest way through a farmers community through those risk-takers.

GLOSSARY

Agronomy
The science of soil management and crop production

Amendment
A substance mixed in the soil to improve its properties

Anion
A negatively charged particle formed when a salt dissolves in water.

Bhal
Fertile sediment deposited by canal water

Calibration of a model
The procedure of modifying model parameters so that the output from the model is some measure of best fit

Capillary rise
Upward movement of water in the soil profile from the saturated zone as a result of surface tension in soil pores.

Cation
A positively charged particle formed when a salt dissolves in water.

Collinearities
Relations that occur between assumed independent variables.

Desi
Local cotton variety (*Gossypium Arboreum* L., *Tree cotton*)

Drill
Mechanical tool used for sowing in regular lines

ECe
Electrical conductivity of the saturated soil paste extract.

Electrical conductivity
The ability of a soil, water sample of solution to conduct electricity
It is proportional to the concentration of salts dissolved in solution and is measured in units of µS(iemens)/cm, mS/m and dS/m, which is equivalent to mmhos/cm. The SI-unit is mS/m. Approximately one dS/m or mmhos/cm corresponds to about 640 mg/l total dissolved solids.

Evaporation
General Physical process for the change of water from a liquid to a gas (vapour) form and its subsequent loss to the atmosphere.
Agronomy Evaporation from the soil surface.

Evapotransiration
Process of water vapour transfer into the atmosphere from vegetated land surface
It includes water evaporated from the soil surface and water transpired by plants.

Fallow
Land left unseeded after being cultivated.

Fodder
Crops which are suitable as food for livestock.

Germination
Emergence of shoot and root from a seed.

Hard pan
A compacted layer in the subsoil.

Hydraulic conductivity
The rate of flow of water through a unit cross-section of soil under a unit hydraulic gradient.

Hydraulic gradient
The change in hydraulic head per unit distance

Hydraulic head
The height to which water rises in a well which is not being pumped It is a measure of head or pressure in that part of an aquifer open to a well at a specified time.

Infiltration
The downward entry of water into the soil expressed as an one dimensional vertical flow.

Inputs
General: Resources allocated to a crop.
In this report: Fertiliser, spray and seeds. So water, labour and machinery resources are mentioned separately.

Ion
An electrical charged atom or group of atoms.

Kacchi rauni
When the soil is hard after the harvest of the wheat the farmers apply some two inches of water in order to ease water infiltration.

Kharif
The summer season which spans over six months from April to September. Main Kharif crops are cotton and rice.

Killa
Local term for an area slightly more than 1 acre.

Leaching
The process of removal of soluble material by the passage of water through the soil.

Leaf area index
The ration of the total surface area of a plants leaves to the ground area available to the plants.

Levelling
Soil cultivation practice carried out in order to level the plot and flatten the topsoil.

Lint
The fibre of cotton. It is remaining once the seeds are removed from the seedcotton.

Mogha
The inlet structure were canal water from the distributary is transferred to the watercourse.

Nakkha
The inlet structure were water from the watercourse enters the farm.

Objectives
Is understood in a socio-economic way as the goal of the production activities. For instance, objectives can be profit maximisation, land reclamation, market-orientated production or subsistence orientated production.

Pakki rauni
Main pre-sowing irrigation, carried out to apply water in the rootzone of the cotton and create a optimum moisture content, so-called watter-condition, of the top soil.

Permeability
A measure of the ease with which a porous material can transmit a fluid (water, air) under a potential gradient. It is a property of the material only and is dependent on the size and shapes of the pores but is independent of the nature of the fluid.

pH
Stands for potential of hydrogen. It is the negative logarithm of the hydrogen-ion activity and is a measure of acidity or alkalinity. A pH of 7 indicates neutrality, less than 7 acidity and more than 7 alkalinity.

Planking
Soil cultivation practice carried out in order to crumble the top soil and therefore reduce evapotranspiration and create a superficial flat soil.

Precipitation
The deposition of water in a solid of liquid form on the earth's surface from the atmospheric sources.

Rabi
The winter season which spans six months from November to April. Main Rabi crop is wheat

Rauni
Common term for a pre-soaking irrigation (See Kacchi rauni, Pakki rauni).

Ripping
Breaking a hard pan that has occurred in the subsoil.

Saline soil
Soil with electrical conductivity of the saturated soil extract greater than 4 dS/m, ESP<15, SAR<13 and pH<8.5.

Saline-sodic soil
A soil which has both high soluble salt and high sodium levels.

Salinisation
The accumulation of salt in soil or in water, to a level that causes degradation.

Salinity
The amount of sodium chloride or dissolved salts in a unit of water. It can be measured in parts per hundred, mg/l of in units of electrical conductivity.

Seedling
A young plant originating from seed..

Seedlint
Also called seedcotton. The cotton seed and lint together, as it is harvested from the open bolls.

Sodium Adsorption ration (SAR)
A relation between sodium an divalent cations, for saturated soil extract or irrigation water. It is used to express the relative activity of sodium, in exchange reactions with soil.

Squarring
The growing stage when the cotton plants forms flower buds.

Squares
Flower buds

Strategy
The production rules that a farmer follows in order to achieve his objective. This production rules determine the allocation of resources to certain activities within the farm.

Transpiration
The loss of water that has been absorbed through plant roots and transported through the plants to the atmosphere from the leaves.

Warabandi
The canal water allocation schedule implying that farmers take turns to use the canal water. In the research area the turn revolves every seven days and in some other areas every ten days. In this report warabandi 1 is starting April 15, so warabandi 2 at April 22.

Waterlogging
saturation of soil with water, resulting from overirrigation, seepage or inadequate drainage.

Watertable
The surface of a groundwater body, the pressure of which is equal to atmospheric pressure. The soil below the water table is fully saturated.

Wattar condition
Ideal moisture condition of the top soil , obtained 3-5 days after the pakki rauni.

REFERENCES

AKHTAR. R., 1986. Pakistan Yearbook, 1991-92. 19th edition, Karachi, East and West publishing company. 551 p.

APPELO, C.A.J. and D. POSTMA, 1994. Geochemistry groundwater and pollution. Rotterdam, A.A. Balkema : 536 pp.

AYERS, R.S., 1977. Quality of water for irrigation. J. Irrig. Drain. Div. Am. Soc. Civ. Eng. 103(IR2): p. 135-154.

AYERS, R.S. and D.W. WESTCOT, 1985. Water quality for agriculture. Irrigation and drainage paper 29, revised. Food and Agriculture Organisation, Rome.

BARRAL, J.P., 1994. Development of a watercourse-based model to assess the canal water supply at the farm level. International Irrigation Management Institute Pakistan.

BASSET, D.M., J.R. STOCKTON and W.L. DICKENS, 1970. Root growth of cotton as measured by P^{32} uptake. Agron. J. 60 : p. 200-203

BELMANS, C., J.G. WESSELING and R.A. FEDDES, 1983. Simulation of the water balance of a cropped soil: SWATRE. *In:* Journal of Hydrology, no. 63 (1983) : 271-286. Elsevier Science Publishers B.V., Amsterdam.

BERGER, J. 1969. The world's major fibre crops, their cultivation and manuring. Centre d'Etude de l'Azote, Zurich.

BHUTTA, M.N. and J. vander VELDE, 1993. Performance of secondary canals in Pakistan Punjab. Research on Equity and Variability at the distributary level. International Irrigation Management Institute, Pakistan.

BOURRIÉ, G., 1976. Relations entre le pH, l'alcalinité, le pouvoir tampon et les equilibre de CO_2 dans les eaux naturelles, Sc, du sol; 3: p. 141-159.

CHERRY, J.P. and H.R. LEFFLER, 1984, *In:* Cotton. KOHEL, R.J. and C.F. LEWIS (eds), 1984. Series Agronomy no. 24. American Society of Agronomy. Madison, USA. p. 512-558

CONDOM, N., 1996. Theoretical knowledge on salinisation. Reference Review. Draft Paper, CIRAD. 26 p.

DABIN, B. 1963 Appréciation des besoins en phosphore dans les sols tropicaux; Les formes du phosphore dans les sols de Côte d'Ivoire. *In:* Cahiers ORSTOM; Sér. Pédol., 1963, 3, p. 27-42.

DAM. J. C. van, J.N.M. STRICKER and P. DROOGERS, 1990. From one step to multi-step. Determination of soil hydraulic functions by outflow experiments.

DOORENBOS, J. and A.H. KASSAM, 1992. Yield response to water. FAO Irrigation and Drainage paper 33, Rome.

EL-ZIK, K.M. and R.E. FRISBIE, 1985. Integrated crop management systems for pest control and plant protection. *In:* MANDAVE (ed) Handbook of natural pesticides: Methods. Vol. 1. CRC Press, Boca Raton, USA.

EL-ZIK, K.M., H. YAMADA, and V.T. WALHOOD, 1980. Effect of management on blooming, boll retention, and productivity of upland cotton, *Gossypium Hirsutum* L. *In:* Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Counc. of Am., Memphis.

ESSEN, A.T. van and C.F. van der FELTZ, 1992. Alternative water management systems in the Punjab. M.Sc. Thesis, University of Technology Delft

FEDDES, R.A., P.J. KOWALIK. and H. ZARADNY, 1978. Simulation of field water use and crop yield. PUDOC, Wageningen, 189 p.

KUPER, M., P. STROSSER, P. GARIN, Z. HABIB, P. KOSUTH, K. RIAZ and G.V. SKOGERBOE, 1996. Analyzing large scale irrigation systems in an Integrated Approach : Application to the Chishtian sub-division. Paper presented at the 11th IPR, International Irrigation Management Institute, Sri Lanka.

GENUCHTEN, M.Th. van, 1980. A closed form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Science Society of America Journal. 44, 5: p. 892-898.

GHASSEMI, F., A.J. JAKEMAN and H.A. NIX, 1995. Salinisation of land and water resources. Juman Causes, Extent, Management and Case studies. CAB International, United Kingdom.

GRIMES, D.W. and K.M. EL-ZIK, 1990. Cotton. *In:* Irrigation of Agricultural Crops-Agronomy Monograph no. 30 (1990) : 741-773. American Society of Agronomy, Madison, USA.

GUINN, G., 1982. Causes of square and boll shedding in cotton. U.S. Dep. Agric. Tech. Bull.

IIMI, 1993. Annual Report. International Irrigation Management Institute, Pakistan.

IIMI, 1996. Soil Survey Report for the Chishtian sub-division. Draft document, International Irrigation Management Institute, Pakistan.

JOHAM, H.E. 1986. Effects of nutrient elements on fruiting efficiency. p. 306-311. *In:* Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Counc. of Am., Memphis.

JOHAM, H.E. and V. ROWE, 1975. Temperature and zinc interactions on cotton growth. Agron. J. 67: p. 313-317.

KIJNE, J.W. and M. KUPER, 1995. Salinity and sodicity in Pakistan's Punjab : a threat to sustainability of agriculture?. *In:* Water resource development, vol. 11, no. 1 (1995), 18 p.

KOHEL, R.J. and C.F. LEWIS (eds), 1984. Cotton. Series Agronomy no. 24. American Society of Agronomy. Madison, USA.

KOOL, J.B. and J.C. PARKER, 1987. Estimating of soil hydraulic properties from transient flow experiments: SFIT user's guide. (submitted)

KUPER, M. 1989 The effect of the quantity and the salinity of irrigation water on cotton production. Volcani Centre, Israel.

KUPER, M. and J. KIJNE, 1992. Irrigation Management in the Fordwah-Branch Command Area, Southeast Punjab, Pakistan. International Irrigation Management Institute, Pakistan.

KUPER, M. and E.G. VAN WAIJJEN, 1993. Farmer's irrigation practices and their impact on soil salinity in the Punjab, Pakistan : is salinity here to stay?. Paper presented at IPR of IIMI Colombo, Sri Lanka. 43 p.

LAMACQ, S., GAL, P.Y. le, BAUTISTA, and B. CLEMMENS, undated. Farmer Irrigation Scheduling : a Case Study in Arizona. CEMAGREF, Montpellier, France.

LATIF, A. and M.A. KHAN, 1976. Effects of soil salinity on cotton (*Gossypium Hirsutum* L.) at different stages of growth. The Pakistan Cottons, 20 : p. 91-104

LAUCHLI, A. and E. EPSTEIN, 1990. Plant response to saline and sodic conditions. *In:* Agricultural salinity assessment and management. -ASCE manuals and reports on engineering practice no. 71 (1990) : p.110-137.

MALIK, M.N.A. and F.A. CHAUDRY, 1991 Cotton growth and seed cotton yield in relation to plant water deficit. Final research report. Central Cotton Research Institute, Multan, Pakistan.

MALIK, M.N.A., M. AHMAD, M.I. MAKHDUM and F.I. CHAUDRY, 1996. Germination of cotton cultivars under saline conditions. Draft report. Central Cotton Research Institute, Multan, Pakistan.

MALIK, M.N.A., M.I. MAKHDUM and M.A. TAHA, 1984. Leaf Area Index and Canopy ground cover in Cotton. *In:* The Pakistan Cottons, Oct. 1984, PIDC, Karachi, Pakistan.

MEMENTO DE L' AGRONOME; 1989. 3rd édition, Ministère de la Coopération et du développement, France.

MEMENTO DE L' AGRONOME; 1991, 4th édition, Ministère de la Coopération et du développement, France.

MERKLEY, 1993. *Quoted in Kuper, Strosser, et al., 1996*

MOLLE and RUF, 1994. *Quoted in Kuper, Strosser, et al., 1996*

MUALEM, Y., 1976. A new model for predicting the hydraulic conductivity of unsaturated porous media. Water Resour. Res., 12: p. 513-522.

PINTUS, F., 1995. Impact of irrigation, salinity and cultural practices on wheat yields. M. Sc. thesis at ESAT, Montpellier, France. International Irrigation Management Institute, Pakistan.

RINAUDO, J.D., 1994. Development of a tool to assess the impact of water markets on agricultural production in Pakistan. Mémoire de DEA, ENSA. Montpellier, France.

ROSCHER, K., 1994. Agro-Irrigation: Plant-Soil-Water-Atmosphere Relations. Wageningen Agricultural University, The Netherlands.

SMETS, S.M.P., 1996. The effects of irrigation management on soil salinity and crop transpiration at the field level by using the agro-hydrological model SWAP93. M.Sc. Thesis Wageningen Agricultural University. International Irrigation Management Institute, Pakistan.

SMITH, M., 1992. CROPWAT : a computer program for irrigation planning and management. FAO Irrigation and Drainage paper : 46, Rome.

STROSSER, P. and T. RIEU, 1993. A research methodology to analyse the impact of water markets on the quality of irrigation services and agricultural production. International Irrigation Management Institute, Sri Lanka. 27 p.

STROSSER, P. and T. RIEU, 1994. Are farmers sensitive to changes in canal operation? A preliminary analysis of farming systems in the Fordwah branch irrigation system, South Punjab, Pakistan. Paper presented at the tenth IPR. IIMI Sri Lanka. 25 p.

STROSSER, P., T. RIEU and J.D. RINAUDO, 1995. Water market development and production strategies : are farmers rationale? Draft document, International Irrigation Management Institute, Pakistan.

SUAREZ, D.L., 1987. Prediction of pH errors in soil water extractors due to degassing. Soil Sci. Soc. Am. J.; 51 : p. 64-67.

TANJI, K.K., editor, 1990. Agricultural Salinity Assessment and Management. American Society of Civil Engineers, New York.

United States Salinity Lab., 1954. Diagnosis and improvement of saline and alkali soils. USDA Handbook 60, Washington D.C.

VALLES, V., Y.A. PACHEPSKY and A.A. PONIZOVSKY, 1991. Invariant criteria for irrigation water quality assessment in arid and semi arid regions. Genesis and control of fertility of salt affected soils. *In:* V.V. DOKUCHAIEV (ed.), ISSZS subcommision on salt affected soils science, Soil Institute, Moscow.

VISSER, S.J., 1996. Canal water distribution at the secondary level. M.Sc. Thesis at University of Technology Delft, International Irrigation Management Institute, Pakistan.

WAIJJEN, E.G. van, 1991. Some relations between irrigation, agriculture and socio-economic context for five watercourses near Hasilpur. International Irrigation Management Institute, Pakistan. 15 p.

WALHOOD, V.T. and R.E. JOHNSON. 1976. Inception of solar radiation by a constant population of cotton plants. *In:* J.M. BROWN (ed.) Proc. Beltwide Cott. Prod. Res. Conf., Las Vegas, Nev. Natl. Cotton Council, Memphis, Tenn. p. 70-71.

WORKING GROUP SWAP, 1994. SWAP93 - Input instructions manual. WAU/SC-DLO, Wageningen.

WÖSTEN, J.H.M. 1987. Description of the water retention and hydraulic conductivity characteristics from the Staring series with analytical functions. Report 2019 Winand Staring Centre, Wageningen.

YADAV, J.S.P., 1987. Management of saline/alkaline soils in India.*Regional Expert Consultation on Management of Saline/Alkaline Soils*. Bangkok, FAO Regional Office for Asia and the Pacific. 42 p.

IIMI-PAKISTAN PUBLICATIONS

RESEARCH REPORTS

Report No.	Title	Author	Year
R-1	**Crop-Based Irrigation Operations Study in the North West Frontier Province of Pakistan** Volume I: Synthesis of Findings and Recommendations	Carlos Garces-R D.J. Bandaragoda Pierre Strosser	June 1994
	Volume II: Research Approach and Interpretation	Carlos Garces-R Ms. Zaigham Habib Pierre Strosser Tissa Bandaragoda Rana M. Afaq Saeed ur Rehman Abdul Hakim Khan	June 1994
	Volume III: Data Collection Procedures and Data Sets	Rana M. Afaq Pierre Strosser Saeed ur Rehman Abdul Hakim Khan Carlos Garces-R	June 1994
R-2	Salinity and Sodicity Research in Pakistan - Proceedings of a one-day Workshop	J.W. Kijne Marcel Kuper Muhammad Aslam	Mar 1995
R-3	Farmers' Perceptions on Salinity and Sodicity: A case study into farmers' knowledge of salinity and sodicity, and their strategies and practices to deal with salinity and sodicity in their farming systems	Neeltje Kielen	May 1996
R-4	Modelling the Effects of Irrigation Management on Soil Salinity and Crop Transpiration at the Field Level (M.Sc Thesis - pulished as Research Report)	S.M.P. Smets	June 1996
R-5	Water Distribution at the Secondary Level in the Chishtian Sub-division	M. Amin K. Tareen Khalid Mahmood Anwar Iqbal Mushtaq Khan Marcel Kuper	July 1996
R-6	Farmers Ability to Cope with Salinity and Sodicity: Farmers' perceptions, strategies and practices for dealing with salinity and sodicity in their farming systems	Neeltje Kielen	Aug 1996
R-7	Salinity and Sodicity Effects on Soils and Crops in the Chishtian Sub-Division: Documentation of a Restitution Process	Neeltje Kielen Muhammad Aslam Rafique Khan Marcel Kuper	Sept 1996
R-8	Tertiary Sub-System Management: (Workshop proceedings)	Khalid Riaz Robina Wahaj	Sept 1996
R-9	Mobilizing Social Organization Volunteers: An Initial Methodological Step Towards Establishing Effective Water Users Organization	Mehmoodul Hassan Zafar Iqbal Mirza D.J. Bandaragoda	Oct 1996
R-10	Canal Water Distribution at the Secondary Level in the Punjab, Pakistan (M.Sc Thesis published as Research Report)	Steven Visser	Oct 1996
R-11	Development of Sediment Transport Technology in Pakistan: An Annotated Bibliography	M. Hasnain Khan	Oct 1996

Report No.	Title	Author	Year
R-12	Modeling of Sediment Transport in Irrigation Canals of Pakistan: Examples of Application (M.Sc Thesis published as Research Report)	Gilles Belaud	Oct 1996
R-13	Methodologies for Design, Operation and Maintenance of Irrigation Canals subject to Sediment Problems: Application to Pakistan (M.Sc Thesis published as Research Report)	Alexandre Vabre	Oct 1996
R-14	Government Interventions in Social Organization for Water Resource Management: Experience of a Command Water Management Project in the Punjab, Pakistan	Waheed uz Zaman D.J.Bandaragoda	Oct 1996
R-15	Applying Rapid Appraisal of Agricultural Knowledge Systems (RAAKS) for Building Inter-Agency Collaboration	Derk Kuiper Mushtaq A. Khan Jos van Oostrum M. Rafique Khan Nathalie Roovers Mehmood ul Hassan	Nov 1996
R-16	Hydraulic Characteristics of Chishtian Sub-division, Fordwah Canal Division	Anwar Iqbal	Nov 1996
R-17	Hydraulic Characteristics of Irrigation Channels in the Malik Sub-Division, Sadiqia Division, Fordwah Eastern Sadiqia Irrigation and Drainage Project	Khalid Mahmood	Nov 1996
R-18	**Proceedings of National Conference on Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan**	M. Badruddin Gaylord V. Skogerboe M.S. Shafique (Editors for all volumes)	Nov 1996
R-18.1	Volume-I: Inauguration and Deliberations		
R-18.2	Volume-II: Papers on the Theme: Managing Canal Operations		
R-18.3	Volume-III: Papers on the Theme: Water Management Below the Mogha		
R-18.4	Volume-IV: Papers on the Theme: Environmental Management of Irrigated Lands		
R-18.5	Volume-V: Papers on the Theme: Institutional Development		
R-19	Detailed Soil Survey of Eight Sample Watercourse Command Areas in Chishtian and Hasilpur Tehsils	Soil Survey of Pakistan IIMI-Pakistan	Nov 1996
R-20	Unsteady Flow Simulation of the Designed Pehur High-Level Canal and Proposed Remodeling of Machai and Miara Branch Canals, North West Frontier Province, Pakistan	Zaigham Habib Kobkiat Pongput Gaylord V. Skogerboe	Dec 1996
R-21	**Salinity Management Alternatives for the Rechna Doab, Punjab, Pakistan**	Gauhar Rehman Waqar A. Jehangir Abdul Rehman Muhammad Aslam Gaylord V. Skogerboe	May 1997
R-21.1	Volume One: Principal Findings and Implications for Sustainable Irrigated Agriculture		
R-21.2	Volume Two: History of Irrigated Agriculture: A Select Appraisal	Gauhar Rehman Hassan Zia Munawwar Asghar Hussain	Jan 1997

Report No.	Title		Author	Year
R-21.3	Volume Three:	Development of Procedural and Analytical Liniks	Gauhar Rehman Muhammad Aslam Waqar A. Jehangir Abdul Rehman Asghar Hussain Nazim Ali Hassan Zia Munawwar	Jan 1997
R-21.4	Volume Four:	Field Data Collection and Processing	Gauhar Rehman Muhammad Aslam Waqar A. Jehangir Mobin Ud Din Ahmed Hassan Zia Munawwar Asghar Hussain Nazim Ali Faizan Ali Samia Ali	Jan 1997
R-21.5	Volume Five:	Predicting Future Tubewell Salinity Discharges	Muhammad Aslam	Jan 1997
R-21.6	Volume Six:	Resource Use and Productivity Potential in the Irrigated Agriculture	Waqar A. Jehangir Nazim Ali	Feb 1997
R-21.7	Volume Seven:	Initiative for Upscaling: Irrigation Subdivision as the Building Block	Gauhar Rehman Asghar Hussain Hassan Zia Munawwar	Apr 1997
R-21.8	Volume Eight:	Options for Sustainability: Sector-Level Allocations and Investments	Abdul Rehman Gauhar Rehman Hassan Zia Munawar	Apr 1997
R-22	Salinisation, Alkalinisation and Sodification on Irrigated Areas in Pakistan: Characterisation of the geochemical and physical processes and the impact of irrigation water on these processes by the use of a hydro-geochemical model (M.Sc Thesis published as Research Report)		Nicolas Condom	March 1997
R-23	Alternative Scenarios for Improved Operations at the Main Canal Level: A Study of Fordwah Branch, Chishtian Sub-Division Using A Mathematical Flow simulation Model(M.Sc Thesis published as Research Report)		Xavier Litrico	March 1997
R-24	Surface Irrigation Methods and Practices: Field Evaluation of the Irrigation Processes for Selected Basin Irrigation Systems during Rabi 1995-96 Season		Ineke Margot Kalwij	March 1997
R-25	Organizing Water Users for Distributary Management: Preliminary Results from a Pilot Study in the Hakra 4-R Distributary of the Eastern Sadiqia Canal System of Pakistan's Punjab Province		D.J. Bandaragoda Mehmood Ul Hassan Zafar Iqbal Mirza M. Asghar Cheema Waheed uz Zaman	April 1997
R-26	Moving Towards Participatory Irrigation Management		D.J. Bandaragoda Yameen Memon	May 1997
R-27	Fluctuations in Canal Water Supplies: A Case Study		Shahid Sarwar H.M. Nafees M.S. Shafique	June 1997
R-28	Hydraulic Characteristics of Pilot Distributaries in the Mirpurkhas, Sanghar and Nawabshah Districts, Sindh, Pakistan		Bakhshal Lashari Gaylord V. Skogerboe Rubina Siddiqui	June 1997