Treated sewagewater use in irrigated agriculture

Theoretical design of farming systems in Seil Al Zarqa and the Middle Jordan Valley in Jordan

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This book is dedicated to my mother
Though you are no longer here, your love and soul continue to surround and support me.

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The Qur'an says: 'Proclaim! (or Read!) in the name of thy Lord and Cherisher, Who created – Created man, out of a leech-like clot: Proclaim! And thy Lord is Most Bountiful, He Who taught (the use of) the pen; taught man that which he knew not.' (96:1-5). I am thankful to God for giving me the strength and ability to read and write which is the basis for the acquisition of knowledge and critical thinking for the benefit of mankind.

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Mohammad Duqqah
December, 2002.

CONTENTS

Preface

Design treated sewagewater using farming systems in Jordan. That was the assignment. Soon after starting the project I discovered that I had to think in two completely different worlds simultaneously: that of the 'hard' experimental-oriented technologist and that of the 'soft' experience-oriented rural sociologists. I was fully confident with the former and almost entirely ignorant of the latter. I discovered after a year that working with farmers was very exciting. I learned that their practical grassroots experiences are as important as the results of formal scientific experiment. Furthermore, their willingness to co-operate opened a new world for me. I discovered from field observation that farmers had some difficulty accepting scientific solutions obtained from controlled experiments and that, on their part, researchers had difficulties with regard to the reluctance of the farmers to accept scientific results. Finally, I found that controversies could be bridged only by accepting farmers' objections to results derived from controlled experiments, and acknowledging that the application of experimental science must endeavour to reflect farmers' everyday reality. This eye-opener caused me, as a technologist, great difficulties. I had, as a consequence, to develop my knowledge on rural agro-sociology first.

This book therefore takes a long step before touching upon its core: 'design a treated sewagewater using farm for Jordan.' This was a necessary step, because what I needed as a technologist will likewise be needed by other technologists. Wageningen University as well as many other European universities speak of the need to integrate Beta and Gamma sciences or, in other words, the integration of hard and soft (process management) knowledge.

This work is structured according to the generally accepted form for scientific reports. On the road towards addressing the work's central issue, however, I have tried to take the reader by the hand and show him (her) what I had to consider before the actual research results could be presented.

I hope that the results presented in this thesis open the way to a real innovation of agricultural production in Jordan. 'Real' means 'acceptable to both farmers and consumers.' 'Innovation' means 'that which Jordan gives the future.'

Chapter 1 - Introduction

Jordan faces a serious shortage of water for consumption, agriculture and industry. Shortages are quantitative and qualitative by nature. Quantitative because population density increases and agriculture for food production increases as well. Along with Jordan's economic development, industrial activities also become more intensive. So, together with decreasing natural or cleaned water reserves, there are increasing amounts of sewagewater. The consequence is a rapid disappearance of Jordan's natural resources (e.g. vegetation, fertile land, clean soils), making country life difficult. Self-sufficient food production will worsen.

The summit on earth and the environment organised by the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in June 1992, was the culmination of a global action programme designed to inform the world community about the global environmental challenges of the nineties. Among others, this summit set objectives for the development of water resources and agricultural production. Of particular significance was the publication of AGENDA 21, which provided a framework for sustainable development into the 21st century. For the term 'sustainable' I apply the FAO (1993) definition of sustainable agricultural development: 'Sustainable development concerns management and conservation of natural resources as well as adaptation of technology and institutions in such a manner that human needs for present and future generations will be covered. Sustainable development preserves un-renewable land, water, plant and animal genetic resources, is environmentally sound, technologically appropriate, economically viable and socially acceptable'. To overcome the problem of over-consumption and pollution, actions recommended in the Dublin Statement (ICWE, 1992a, 1992b) became part of AGENDA 21. The actions contain four guiding principles:

- freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment;
- water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels;
- women play a central part in the provision, management and safeguarding of water; and
- water has an economic value in all its competing uses and should be recognised as an economic asset.

During the recently held UN summit on sustainable development, renewed emphasis was laid on the need, especially in developing countries, to halt current trends in the use of water. This conference again stated in no uncertain terms that governments, in close co-operation with researchers and stakeholders, have an important task in achieveing a balance between the need for clean water and the tendency to use water carelessly, or otherwise waste or pollute it. Furthermore, it was also made clear that there is no time to lose in this matter.

His Majesty the late King Hussein of Jordan's report, submitted to the Earth Summit in 1992, sets out Jordan's commitment to sustainable development. Jordan passed a new environmental law and established the General Corporation for Environmental Protection in 1995, which underlined Jordan's intention to become active in environmental protection. Jordan's Law of Environmental Protection was drafted in 1993 to achieve the principal objectives mentioned in the National Environmental Strategy for Jordan (IUCN, 1991). The law contains basic principles for environmental management. It does not contain, however, any specific standards or regulations for implementation. Recommendations for the formulation of an effective environmental policy are (IUCN, 1991):

- prevent rather than cure pollution problems;
- minimise waste by the rapid introduction of environmentally-friendly techniques, products and production processes;
- stimulate treatment of industrial waste, e.g. by reuse and recycling techniques, and reduction of polluting discharges;
- adopt best available technologies for controlling environmental pollution;
- apply the 'polluter pays' principle by imposing fines for violation of environmental protection laws and regulations;
- apply strict national criteria and standards for defining environmental quality, acceptable emission rates, and consumer products;
- assess environmental impact before the implementation of new development projects;
- integrate the interests of, and foster co-operation between, public authorities, industry, utilities, agri-business, local government and public;
- ensure easy access to all available information about the environment for the public.

Up to the early 1950's the use of water in Jordan was almost entirely limited to domestic and agricultural use. Development of the industrial sector had not yet taken place and, with the relatively limited requirements, there was a positive supply situation in which supply exceeded demands. Since that time impact on resources has grown to an unforeseen level. Increased demands from the municipal sector followed the high natural growth of population and the influx of refugees. Development of the industrial sector over the same period had a similar impact. In the agricultural sector there was a reduction in the country's rain fed production due to successive drought years. Migration of rural populations to urban areas occurred as people sought higher incomes and a better way of life. To meet additional demands for food and increase export earnings, enhanced development of irrigated agriculture was essential. Government involvement was a pre-requisite for investment and infrastructure, and it played a significant role in the development of the Jordan Valley and other areas. For that reason the Jordanian government developed ideas for capacity building on sewagewater valorisation for agricultural production. Egypt and Palestine also became involved. In close co-operation with the Dutch government an education and research programme came into being under the acronym of WASTEVAL.

1.1 The WASTEVAL programme as problem statement

The WASTEVAL project aims at capacity building at the counterpart institutes in the Netherlands, Jordan, Egypt and the West Bank concerning, among others, low-cost treatment technologies for a number of objectives including agricultural production. Its focus is the development and proper application of low-cost treatment and recovery methods for waste and sewagewater, originating from municipalities, small-size communities and, to a lesser extent, agro-industries. Irrigation and fertilisation of arid areas with well-treated sewagewater should lead to a significant increase in agricultural production.

The project had to develop specialised staff at MSc, PhD and post doc levels. Moreover, awareness about sewagewater treatment technologies among government and private sector professionals (e.g. short courses, workshops and seminars) had to be raised in general and curricula of relevant education and training institutions in the target countries had to be adjusted.

The agricultural section of the WASTEVAL programme has four objectives:

- search for possibilities that make treated sewagewater for irrigation a viable option;
- implement such possibilities in practice;
- enable farmers to exploit these possibilities on their own and
- deliver recommendations for government, institutions and farmers about how treated sewagewater could safely be applied in practice.

These objectives address the Dublin principles exactly (see page 1).

Treated sewagewater use in irrigated agriculture should be economically feasible and environmentally sound. The programme holds to the view that treated sewagewater use can:

- provide additional sources of water, nutrients and organic matter for soil conditioning and agricultural production;

- improve the environment by the elimination or reduction of discharges to surface water;
- conserve freshwater sources; and
- improve returns on investment in sewagewater use and irrigation.

Despite all of the above-mentioned advantages of treated sewagewater as a resource, it was not used in Jordan for the following reasons:

- lack of information about its benefits;
- fear of possible health risks;
- cultural bias;
- lack of a method to analyse the economy of treated sewagewater use comprehensively;
- negative experience with treated sewagewater use in areas where this use occurs in uncontrolled or poorly designed conditions; and
- no overall strategy for introducing treated sewagewater into agriculture.

So far, efforts to improve the situation are technological in nature, like the introduction of water conservation techniques and more water efficient methods of production for example. Enhancing the capacity of mainstream treatment systems of sewagewater is another example. Research on anaerobic sewagewater treatment has therefore been increased in order to enlarge the number of options for managing the problem (Haandel & Lettinga, 1994; Wang, 1994). A third option may be the direct use of treated sewagewater. This option considers treated sewagewater not as waste, but as water source and a nutrient-enriched water resource applicable in crop production. A great advantage involved is that treated sewagewater may help reduce the farmer's production costs. This factor might make treated sewagewater an attractive option for farmers. The practical application of treated sewagewater, however, would by no means be a simple process. A considerable amount of information would have to be compiled prior to any application; information pertaining to the technical, environmental and cultural aspects involved, as well as issues of health.

1.2 Societal problem addressed

The present project, within the framework of the WASTEVAL programme, formulated three main objectives:

- through co-operation with farmers create farming systems that in the main use treated sewagewater for irrigation;
- teach farmers how to learn from their own experiences; and

- give advice on how policymaking could contribute to an ongoing transformation of currently unsustainable forms of agricultural production into improved, more sustainable ones.

The results acquired must provide reliable information for policymaking by all relevant Jordanian stakeholders involved in the use of treated sewagewater: government, policy makers, scientists, teachers, extensionists and farmers. The limiting conditions were:

- production costs of the farms involved must decrease relative to present farming systems in order to make innovations in irrigation attractive for farmers;
- farmers must voluntarily accept the design (in terms of safety and cultural acceptability);
- the new design must be technologically applicable; and
- the design must be independently manageable.

1.3 Structure of this book

As the WASTEVAL programme is about research and education concerning water scarcity in Middle East countries and this book reports specifically on research results obtained in Jordan, we had to begin by describing Jordan's actual water deficit. Chapter 2 is designed to give the reader a sense of urgency: somebody must do something, and quickly, in order to stop the increasing shortage of clean water in Jordan. Chapter 2 also demonstrates that Jordanian agriculture, as a big polluter of natural resources and according to the 'polluter pays' principle, must first learn how to produce efficiently while maintaining low application levels of synthetic agro-chemicals.

Chapter 3 provides a model for involving Jordanian farmers themselves in decreasing water use and pollution during crop production. It is assumed that sewagewater, after certain pre-treatment, carries along sufficient nutrients that could function as fertiliser and as an adequate water dose during primary production. The supply of chemical fertiliser could as a consequence be considerably reduced. Three advantages thus emerge. The cost of cleaning sewagewater is reduced, the variable costs of farmers decrease and the water demand of the agricultural sector shifts from clean (cleansed or natural) water to treated sewagewater. The model assumes that the aforementioned advantages only manifest themselves when the producing and using sectors of treated sewagewater work together. Co-operation will lead to a harmonisation of end terms for the goals of sewagewater in terms of quality, to recognising and accepting each other's working procedures and to cohesion among investments for the intake and distribution of sewagewater. Co-operation will also lead to an effective sharing of knowledge, the sharing of concepts and definitions, as well as to efficient regulation and control of the resource. Co-operation will not emerge by itself. The respective sectors are much too different for that to happen. The model therefore assumes that the government must foster and facilitate such a co-operation.

Chapter 4 translates the theoretical framework given in chapter 3 into six research questions that had to be addressed during the project. Each of them is progressively answered in chapters 5 through to 10. These chapters have been set up as if they were separate publications. The reader will notice that some overlap may be found between them. This was, considering the holistic approach of the project, unavoidable. Moreover, overlap also indicates that our approach in relation to the problem statement as defined in chapter 3 occurred in an integrated way.

Chapter 5 describes the method employed in looking for a suitable research area. Chapter 6 illustrates what consequences of working with farmers on their fields had to be taken into account when starting the project. Chapter 7 demonstrates that treated sewagewater can meet crop demands in terms of nutrients and water, without a chemical fertiliser supply. Chapter 8 presents how small-scale farmers in the research area redesigned their farms to enable the safe and efficient use of treated sewagewater. This particular chapter is based on the prototyping technique used in many European countries. Chapter 9 presents an analysis of strengths and weaknesses concerning the redesigned farms. Chapter 10 shows the role of stakeholders in the safe use of treated sewagewater on farms. This chapter emphasises the co-operation between the producing and using sectors of treated sewagewater respectively. The study ends with a presentation in Chapter 11 of conclusions and recommendations in terms of a proposed approach for the use of treated sewagewater in irrigated agriculture.

1.4 Definitions

This book contains a number of frequently used terms relating to water. The following table provides an inventory and clarification.

Table 1.1 Water definitions

Term	Definition
Surface water	A general term describing any body of water that is found flowing or otherwise lying on the earth's surface, such as streams, rivers, ponds, lakes and reservoirs. Surface waters originate from a combination of sources: (1) surface run-off rainfall which has fallen onto the surrounding land and that flows directly over the surface into a body of water; (2) precipitant rainfall that falls directly into a body of water; (3) interflow excess soil moisture draining into a body of water; and (4) water-table discharge where there is an aquifer below the body of water and the water-table is high enough. In this case the water will discharge directly from the aquifer into the body of water.
Ground water	Water from aquifers or other natural underground sources. Ground water is derived from precipitation directly as infiltration, or indirectly via a run-off mechanism, and therefore forms part of the hydrological cycle. The ground water will eventually discharge into a spring, a river, a lake, or the sea.
Sewagewater	A dilute mixture of domestic waste. Its composition is extremely complex and varies considerably depending on the amount of water used per head of population.
Treated sewagewater	The effluent of a treatment plant, a place that treats sewagewater accruing from domestic sources. It is essentially concerned with the reduction of organic loading that would arise if raw sewagewater were allowed directly into watercourses. The main objective of sewage treatment is to reduce the strength (concentration of pollutants) of sewage to a sufficient degree so that this can be safely discharged into natural waters without causing a nuisance or offence.
Natural water	Water as it occurs in the atmosphere as well as on and below the surface of the earth in which there has been no modification by humans.
Poor quality water	This includes drainage water, saline water, saline ground water, treated sewagewater, and other sources that do not meet the quality criteria for certain uses. In some instances poor quality water may be used by agriculture to save high quality water for other uses.
Mixed water	Water resulting from the mixing of poor quality water and good quality water to increase water supplies while maintaining an acceptable quality.
Municipal water	Sewagewater derived from domestic, commercial, and industrial sources.

As this research project considers all kinds of sewagewater not as a waste but as a resource, we will operate 'treated sewagewater' as the most appropriate term throughout this work. It indicates sewagewater that has been mixed with clean water without losing its useful nutrient content in the process.

Chapter 2 - Water in Jordan

Jordan has very limited water resources, probably the lowest in the world on a per capita basis. Available water resources per capita is, among other reasons, a result of population growth, and is projected to fall from over 170 cubic metres per capita per year (m^3 / cap / yr) at present to only 91 m^3 / cap / yr by 2025 (Table 2.1). Jordan would thus fall into the category of having an absolute water shortage. Climatic factors and limited ground and surface water mean that Jordan has inherently restricted water resources. This situation will worsen in the coming years despite all technology, investments and commercials promoting 'care with water'. This chapter expresses an explicit sense of urgency concerning Jordan's present and future water sources. It ends with conclusions on the possible role of agriculture in cutting down Jordan's water scarcity.

Table 2.1 Availability of water in the Middle East

Country	**1960**	**1990**	**2025**
	m^3 / cap / yr		
Egypt	2,251	1,112	645
Israel	1,024	467	311
Syria	1,196	439	161
Jordan	529	224	91

Source: World Bank Report, Water Sector Review, 1997

2.1 Jordan's water resources

Water resources come from three sources: surface water (stream flow from rivers, wadis and stored surface water in dams), ground water and sewagewater.

2.1.1 Surface water

Surface water flows in rivers as flood flow and permanent streams. Permanent river, wadi and spring flows vary monthly, and are determined primarily by the quantity and duration of rainfall. The total flow from all surface water resources in Jordan is 715 million m^3, out of which the base flow constitutes about 353 million m^3 per year, the flood flow 332 million m^3 per year, and spring flow 225 million m^3 per year (World Bank, 1997). Jordan's surface water is distributed unevenly in 15 basins, ranging from 285 million m^3 in the Yarmouk and Adasiya Basin to 2.2 million m^3 in the southern desert basin. The Yarmouk Basin accounts for 40% of the total surface water in Jordan. This figure includes water arriving in the Syrian part of the Yarmouk Basin. Since this water forms the major tributary of the King Abdullah Canal, it is considered to be the backbone of development in the Jordan Valley. Other major basins include Zarqa, the Jordan River's side wadis, Mujib, the Dead Sea, Hasa and Wadi Araba. The government has invested heavily in the development of surface water resources, with priority given to the construction of dams and irrigation projects in the Jordan Valley. The flow in the Jordan River is estimated at 1013 million m^3 per year. Salinity is extremely high and its use as a water resource for Jordan can be regarded as nil (World Bank, 1997).

2.1.2 Ground water

Ground water is another major source in many parts of Jordan. It comprises both renewable and non-renewable resources. Jordan's ground water is distributed among 12 basins. At present, some renewable ground water resources are exploited at maximum capacity. In some cases this happens even beyond the safe yield level. Many studies estimate the safe yield of renewable ground water resources at 275 million m^3 per year (Bani-Hani, 1992).

2.1.3 Sewagewater

Sewagewater, treated before use, emanates from fourteen existing sewage treatment plants and forms an important component of Jordan's water resources. In 2000 about 87 million m^3 of sewagewater was treated and discharged into watercourses and used directly for irrigation, mostly in the Jordan Valley (personal communication, Ministry of Water and Irrigation). About one third of municipal water supplies to the Greater Amman area return to the main treatment plant, Khirbat Al-Samra. This plant runs at almost twice its rated capacity. The result is that the quality of treated sewagewater is poor. Sewagewater quantities increase with population growth, intensity of water use, and the development of sewage systems for use by the inhabitants. By 2025, when the population will amount to 10 million, and the number of people making use of sanitation services will have increased from the current 45% to 65% of the total population, an estimated 237 million m^3 of sewagewater will be produced per year (World Bank, 1997).

Sewagewater treatment in Jordan occurs primarily by means of stabilisation ponds. Due to evaporation, this system guarantees the enhancement of salinity levels in the sewagewater involved. The treated sewagewater of Khirbat Al-Samra has an average salinity of 1,180 ppm. This is too high for cropping in cases where treated sewagewater is used. Our project has to take such data into account.

2.2 Present use of water resources

Agriculture, urban areas and *industries* are currently Jordan's biggest water consumers. Tables 2.2 through to 2.5 present data concerning the supply and demand of water in Jordan in the next decades. They are based on the following definitions for water supply and water demand. Water supply is the actual amount of water directly delivered for use. This can of course be less than the amount actually needed. It may also be lower or indeed higher than the amounts available from ground and surface water. Water demand is the amount of needed water. What is needed can be derived from targets for:

- water consumption per capita per year;
- size of land area to be irrigated; or
- cropping intensity as determined by government or industrial processes.

Table 2.2 Water Supply in million m^3 per year

Year	Supply for municipal and industrial sector	Supply for agricultural sector	Total supply for both sectors
1998	275	623	898
2005	363	679	1042
2010	486	764	1250
2015	589	693	1282
2020	660	627	1287

Source: World Bank, 2001

Table 2.3 Expected treated sewagewater use in the Jordan Valley and the Highlands in million m^3

Year	Jordan Valley	Highlands	Total
1998	56	11	67
2005	65	43	108
2010	110	66	176
2015	123	84	207
2020	137	95	232

Source: World Bank, 2001

Table 2.4 Water Requirements in million m^3 per year

Year	Municipal and Industrial (M&I) Requirement	Agricultural Requirement	Total Requirement
1998	342	863	1205
2005	463	858	1321
2010	533	904	1437
2015	639	897	1536
2020	757	890	1647

Source: World Bank, 2001

The difference between supply and demand is shown in table 2.5. It makes clear that the water deficit in Jordan is an acute problem.

Table 2.5 Water Supply and Requirements in million m^3 per year

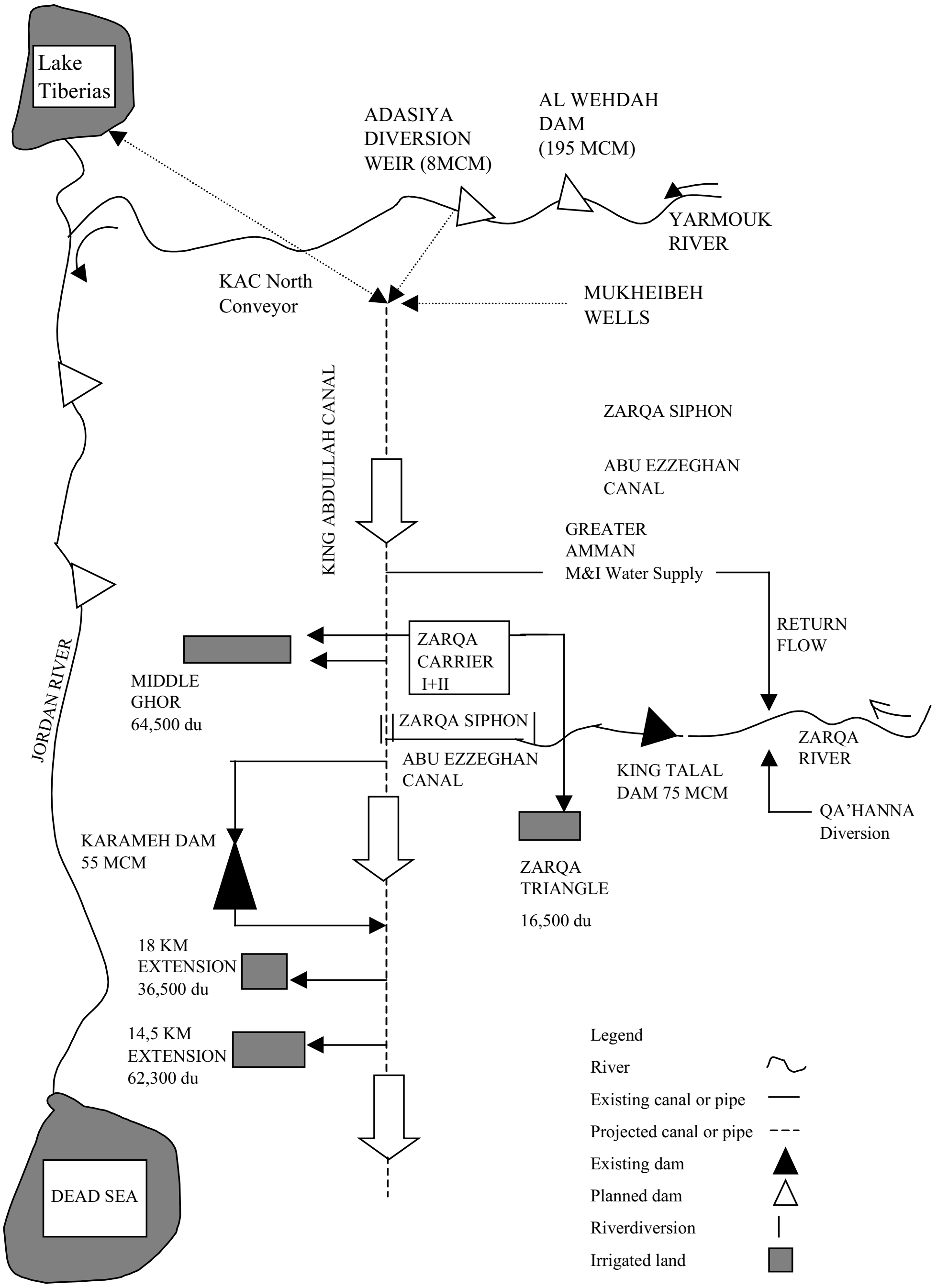
Year	Total Requirements	Total Supply	Deficit
1998	1205	898	- 307
2005	1321	1042	- 279
2010	1436	1250	- 186
2015	1536	1283	- 253
2020	1647	1287	- 360

Source: World Bank, 2001

2.2.1 Agricultural use

Large irrigation projects were implemented in Jordan in 1958, soon after the government had decided to use part of the Yarmouk River system for the construction of the East Ghor Canal project (now named King Abdullah Canal). The canal was 70 km long in 1961, and was extended three times between 1969 and 1987 to 110.7 km. The King Abdullah Canal has put more land under irrigation. In addition, five other dams were constructed in side valleys making possible the irrigation of much more land (see Map 2.1). More water was also made available by wells, drilled by private enterprises and by the Jordan Valley Authority. Wells were needed for domestic use and for irrigation. The highlands of Jordan depend mainly on ground water resources for irrigation.

Irrigation accounts for more than 70% of all required water use. Family farms in the highlands are irrigated by ground water from private wells. The public irrigation system in the Jordan Valley, managed by the government, uses surface water and treated sewagewater. Both systems expanded rapidly. Highland irrigation expanded from 3,000 hectares in 1976 to an estimated 33,000 hectares at present and accounts for about 60% of ground water use. Earlier over-extraction stopped the further expansion of groundwater use while licenses have served to reduce extraction levels since their introduction in 1993. The use of ground water in agriculture stabilised. New wells came into operation and replaced the wells that had become exhausted or saline. A programme for measuring water extraction from wells is underway. It is expected that overuse of ground water will stop in the near future.



Map 2.1 Location of all water resources from which future water supplies are expected

Sewagewater use in irrigation combines the techniques of two disciplines: sewage disposal and irrigation. Both disciplines are routinely developed and implemented through valid, established methods and guidelines. But guidelines for sewagewater use in irrigation cannot mirror both disciplines.

The benefit of using sewagewater in agriculture is the recycling of water and nutrients. In arid and semi-arid areas, sewagewater use in irrigation may increase farm production significantly

(Paranichianakis et al., 2000; Gori et al., 2000; Beltrao et al., 1999 and Haruvy, 1998). At a flow of 140 litres per capita (l/c/d) a population of 100,000 people would generate about 5 million m^3 of sewagewater per day. This would be enough for the irrigation of 1,000 hectares at a rate of 5,000 m^3 per hectares per year, conditional upon efficient irrigation methods being applied. With inefficient methods, the same amount of water could irrigate 250-500 hectares in arid regions.

Sewagewater contains nutrients and trace elements necessary for plant growth (Papadopoulos, 1993). Five million m^3 of sewage contains approximately 250,000 kg of nitrogen, 50,000 kg of phosphorus, and 150,000 kg of potassium (Khouri et al., 1994). Whether additional fertiliser is required depends on the particular crop being irrigated. Nutrient deficiencies in the soil can be compensated for by the nutrients in the sewagewater. This is significant to situations where chemical fertilisers are either unavailable or where subsistence farmers cannot afford them. Nutrients in sewagewater may therefore reduce costs for chemical fertilisers and may improve farm profitability. But this would only be the case if the sewagewater involved can be used in a non-toxic and safe way.

Costs for sewagewater use in irrigation arise from:
- irrigation technologies required;
- restrictions to the production of low-value crops; and
- measures required for the protection of public health.

For example, sewagewater use for tree crops needs little or no treatment, but financial returns are lower than those from vegetables. Sewagewater use for cash crops, however, requires substantial investment in treatment and/or irrigation facilities, and in health protection measures for farm workers.

Nutrients, trace elements and other salts in sewagewater may occasionally reach levels that are detrimental to crops or soils. In such cases, alternative crops must be selected or exceptionally clean water added. Such measures decrease profitability for farmers. The major chemical elements and aspects in question are discussed briefly below.

Nitrogen: water and nitrogen requirements of plants vary during the growing season. If applied sewagewater contains higher levels of nitrogen than needed according to a particular crop's water requirement, for instance, then a situation of over-manuring occurs. An excess of nitrogen has the following detrimental effects:
- poor fruit production (e.g. tomatoes).

- vulnerable to fungi, viruses, insects and bacteria.
- more weeds.
- ground water contamination.

Trace elements: Heavy metals in sewagewater have an impact on the quality of produce. Two elements are of particular interest: boron and molybdenum (Bouwer and Idelovitch, 1987). Boron in sewagewater is toxic for plants. Molybdenum accumulates in forage and may reach toxic levels. Other elements, e.g. those accruing from industrial wastes, are dangerous if discharged into municipal sewers.

Salinity: Water salinity may reduce crop yield. Salinity of sewagewater is generally 200-400 mg / l[1] higher than the salinity of freshwater supplied to a city. In general, however, the use of sewagewater does not cause more salinity than freshwater irrigation. There are a number of reasons for this:

- salinity of sewagewater is not much higher than that of freshwater;
- salts are generally leached out from the root zone by excesses of water that inefficient irrigation systems currently give rise to; and
- organic matter present in sewagewater is thought to buffer the negative effects of salts.

Environment. Irrigation with treated sewagewater should be considered not only for agricultural purposes. Irrigation with treated sewagewater in agriculture could also be seen as an alternative to discarding public waste. This vision springs from the idea that the environment has a cleaning and buffering capacity. Risks to the environment when treated sewagewater is applied are (Al-Jayyousi, 2002; Angelakis, 2001; Haruvy, 1998; Shuval et al., 1997 and Kontos et al., 1996):

- spread of pathogens;
- oxygen depletion by organic contaminants;
- introduction of chemicals into susceptible ecosystems (mainly water sources); and
- the overloading of an environment's carrying capacity.

Most modern treatment processes used in industrialised countries are designed to reduce the chemical and biodegradable sewagewater constituents, but they do not significantly effect pathogen removal. Adequate pathogen removal can be achieved, however, with a low-cost technology (anaerobic or waste-stabilisation pond systems).

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[1] milligrams per litre of total dissolved solid (TDS)

The disinfecting of sewagewater by chlorination is uncommon in many countries because of the high cost and technologies involved. A negative aspect is that chlorine reacts with humic compounds in sewagewater and produces trihalomethanes. Chloroform, the most abundant of these trihalomethanes, is reported to be carcinogenic. Thus, sewagewater treatment followed by irrigation provides public health and environmental benefits that cannot be achieved by treatment (including modern methods) and disinfection alone.

The controlled application of treated sewagewater on land also reduces the chance that organic and chemical contaminants enter surface and ground water. Crops absorb substances such as nutrients and prevent them running off or leaching into ground water. Secondly, the soil filters out pathogenic organisms and trace elements. These advantages occur with a minimum of technical input and without potentially harmful side effects (for instance chlorination).

Environmental aspects of sewagewater use cannot be confined to pollution issues alone. Irrigation of non-agronomic crops such as grassland and forests is an option for:

- reducing desertification;
- creating greenbelts;
- the reforestation of unproductive and infertile areas;
- controlling soil erosion; and
- the production of timber.

Legislation. Most countries where sewagewater use is practiced in irrigation have public health regulations to protect both the agricultural workers and the consumers of irrigated crops. Regulations may prohibit such irrigation within specified periods before harvesting, make appropriate clothing (such as boots) compulsory, and provide healthcare for employees. In most industrialised countries, those standards are met without major difficulty. Technology and operational capacity is generally available and inspection agencies monitoring sewagewater quality provide permanent security.

In developing countries, on the other hand, specialised equipment necessary for sewagewater of a certain quality is often not available, or not maintained. Regulatory agencies, if they exist, can seldom enforce prescribed standards. Irrigation with sewagewater is therefore badly controlled in such countries. As a consequence, agricultural workers are permanently exposed to risks.

2.2.2 Urban areas and industry

Increasing urban use of water will result in increasing amounts of sewagewater, which, if adequately treated, can be used for irrigation. The importance of treating and making use of sewagewater cannot be over-emphasised. Sewagewater use, in most cases, is difficult to calculate. Extraction takes place from the watercourse downstream of the treatment plant. We know that salinity, faecal coliform bacteria and heavy metals are found in high concentrations downstream of Khirbet As Samra to the junction of the Zarqa River with the King Abdullah Canal. Water quality as such is detrimental for non-restricted farming in the lower part of the Jordan Valley. Required sewagewater quality, and hence the selection of treatment technology, is not based on the standards for the safe application of sewagewater for agricultural utilisation. A high priority must be given to the development of a policy and strategy for sewagewater treatment and use. Waste stabilisation ponds appear suitable for use in Jordan for the moment. However, it is increasingly clear that evaporation and seepage causes unacceptable rates of water loss. Waste stabilisation ponds must either not be overloaded, or become better designed.

A number of recent innovative developments in sewage treatment technologies are now well proven and appear to be suitable for application in Jordan. Pilot projects to demonstrate their suitability are underway. An interesting approach concerns the anaerobic reactor. Sewagewater generated in Jordan is characterised by high strength Biological Oxygen Demand (BOD) in the range 600-1000 mg/l, and high temperature, due to the prevailing climate. Processes based on aerobic processes (activated sludge, aerated lagoons) are expensive to operate because they require a lot of energy and increase electricity costs. Moreover, they need much land for the construction of maturation ponds, making such land unusable for other purposes. The anaerobic reactor (digester) might be a good alternative. India and South America have installed quite a number of them. From their experiences we see the following (Lettinga, 1996; Van Lier and Lettinga, 1999):

- high efficiency of BOD and Suspended Solid (SS) removal;
- a short hydraulic residence time of one day or less;
- a long solids residence time of the order of one year produces highly stable, easily dewatered and inoffensive sludge;
- removal of Helminth ova (the only such process apart from expensive filtration or storage ponds of more than 8-10 days retention time);
- no energy requirement;
- generation of usable volumes of biogas in the case of larger facilities;
- conversion of nutrients to easily assimilated forms of subsequent agricultural use; and

- excellent performance at sewage temperatures above 20 °C and adequate performance if temperatures drop during colder months to 15-16 °C .

2.3 Future use of water resources

The future of Jordan's water resources depends on the *present balance* between supply and demand. It also determines Jordan's *scope* for successful policymaking in the future. The future use of water resources is also dependent upon the *limiting factors* that Jordan must face when creating policies for improved use of scarce water.

2.3.1 Present balance

Supply and demand of water in Jordan are still out of balance, despite all aforementioned efforts to enhance water supplies. The imbalance will continue as a result of the:

- rapid population growth (birth rate and influx of refugees);
- improvement in living standards;
- increasing industrial demand for water; and
- intensification of cropping in the Jordan Valley.

The limited number of options for increasing water supply in the future, coupled with the need to reduce extraction aquifers, requires an integrated approach to the planning of water use. 'Integrated' here means the co-operation between all stakeholders involved in water consumption and sanitation. Consumers should be taught how to be careful in their use of water. Sanitation officers should become aware that over-dimensioning of plants and distribution networks raise costs without bringing any added value. Supply and demand must be harmonised, and the interests of all stakeholders involved understood to the fullest extent possible. The only further resources that could be made available are:

- the exploitation of non-renewable ground water resources;
- desalination of brackish water and ground water;
- the use of treated sewagewater; or
- a search for deep lying aquifers.

Treated sewagewater use is widely practised, but there are problems with quality and consumer acceptance. A national strategic plan for sewage management is needed. Such a plan must set the standards for:

- the qualities of all irrigation water, water used in, or resulting from, industrial processes and drinking water;

- appropriate treatment;
- appropriate limitations on agronomic use;
- health issues;
- environmental issues;
- price policy;
- prioritisation of investments to be made in the future; and
- appropriate water management.

Social-economic aspects involved in a sewagewater project must relate in particular to two factors, vital for project planning and implementation:

- the perceived need for sewagewater as a substitute for national water; and
- the degree of acceptability of sewagewater use by the people who will be affected by the project.

A physical, natural resources-oriented survey complemented by a socio-economic study of the communities effected by the sewagewater project together indicate the real need for the use of treated sewagewater. The acceptance of treated sewagewater use seems to be influenced by the values and customs of the people involved, as well as by the potential benefits arising from such use.

The idea of irrigating with treated sewagewater does not appear to arouse appreciable repugnance where it is being implemented or proposed, although in certain areas some farmers refused to substitute treated sewagewater for available freshwater. Other farmers of similar background in the same area did accept treated sewagewater for irrigation purposes. Attitudes involved reflect a personal, rather than a cultural, bias.

The effect of religion on the feasibility of using sewagewater in Islamic countries is frequently cited as an example of a socio-cultural factor that may limit opportunities for treated sewagewater use in such countries. However, information from most Islamic countries of the Middle East shows that treated sewagewater is indeed used, principally for irrigation only (Abderrahman, 2000; Biswas and Arar, 1988; Ali, 1987; CLIS, 1978). Religious authorities there generally reject attempts to institute other uses of treated sewagewater besides irrigation. Applications such as toilet flushing are deemed unacceptable as people risk being contaminated by residues of the impure flushing water.

The search for farming systems that could meet the many goals mentioned above requires (Lee, 2002):

- integration of agro-technical, agro-ecological and agro-economical knowledge;
- joint agreement on normative objectives among stakeholders;
- empirical team-work to test, adapt and refine those farms under real commercial conditions; and
- promotion of the concept for rural development.

Treated sewagewater use in irrigated agriculture should be economically feasible and environmentally sound. The programme holds to the view that treated sewagewater use can:

- provide additional sources of water, nutrients and organic matter for soil conditioning and agricultural production;
- improve the environment by the elimination or reduction of discharges to surface water;
- conserve freshwater sources; and
- improve returns on investment in sewagewater use and irrigation.

2.3.2 Scope for improving the water balance

Agriculture, being both the biggest user and polluter of clean natural water in Jordan, could be approached according to the so-called ‘polluter pays’ principle (Brom, 1999) This principle states that production farms must do their utmost to become sustainable: must make no use of external inputs beyond the level that the production process can remove by harvests. This ‘equilibrium principle’, well known in Europe, is a tool for the creation of farms that become progressively more efficient. That is to say, farmers are able to obtain higher production levels with the same amounts of fertilisers, pesticides or water (Rossing et al., 1997). ‘Improving the water balance’ thus means: ‘let present and highly polluting farming systems in Jordan become progressively more efficient, until farm production reaches a stage at which it occurs with minimal or negligible agrochemical input.’ The scope for such a development lies in farming systems research, governmental stimulation measures and suitable legislation. Many countries already demonstrate the success of this approach (Vereijken, 1997). But is it applicable under Jordanian circumstances too? In addressing this question I undertook an investigation of thought and opinion current among farmers and hydrologists in different regions of Jordan regarding their expectations for the future. I asked them the question: ‘what do you expect will happen if no change is effected in Jordan with regard to the present use of available natural resources in our country?’

Table 2.6 Environmental concerns in agricultural production as perceived and identified by stakeholders. This table demonstrates the seriousness of Jordan's environmental problems.

Region*	**Environmental concerns**
Jordan Valley	Use of sewage in irrigation pollutes soils. Misuse of technology (chemicals, plastic). More population centres, sewage systems and population burden. Increased soil salinisation. Deteriorating quality of irrigation water. Deterioration of soil fertility. Climatic change (fluctuating rainfall, eastern winds and frost formation). More floods from side valleys. Trespassing on government lands.
Mountainous Highlands	Using sewage in irrigation. Depletion of ground water and insufficient use of water for various purposes. More population centres, sewage systems, pollution, and use of agricultural land for urban expansion. Using fertilisers, insecticides and plastic houses on irrigated lands. Climatic change; more frost, strong winds and rainfall fluctuation. Soil erosion by water increase. Misuse of lands and destructive agricultural practices. Waste disposal sites and ground water source pollution. More laws governing agricultural resource protection, land management and fragmentation of property, so higher chance of illegal activity. Overgrazing and mountainous grazing land deterioration.
Marginal Steppe area	More treatment plants, sites and sewage use burden overall soil use. Depletion and salinisation of ground water and low irrigation efficiency. Desertification and climatic elements, including limited and fluctuating rainfall, and high evaporation rate. Soil erosion by water and soil salinisation increase. Overgrazing and cutting of grazing shrubs. Waste disposal sites and sewage systems. Misuse of lands and trespassing on government lands. Distribution of population centres. Laws protecting agricultural resources and their implementation.
Badia	Shortage, misuse and poor quality of water. Climate (evaporation, frost and wind). Soil salinisation and expansion of sand and gypsum lands. Soil erosion by wind and water. Destruction of plant cover by overgrazing, cutting and vehicles. Desertification, which is increasing progressively. Population centres.

* The different physiographic regions of Jordan

Table 2.6 gives an overview of all issues mentioned by stakeholders concerning the situation in Jordan in the absence of any further development(s).

It is clear from the above table that the vast majority of respondents were very concerned about an imminent scarcity of water resulting from the exhaustion and contamination of sources. It is also clear that the issue of water as a whole has many more repurcussions than had up to now been assumed.

2.3.3 Limiting factors for improving the water balance

Water resources become severely scarce. These decline both in quality and quantity. The country is largely arid or semi-arid. About 96% of the land receives less than 300 mm of precipitation a year. This makes irrigation crucial, since agriculture consumes almost 70% of all available water. Investment in irrigation in the 1970's and 80's resulted in the intensification and increase of agricultural outputs. This expansion was accompanied by shifts in cropping patterns in favour of cash crops, which further increased income. However, no additional sources of surface water exist that can be economically harnessed, and the current level of ground water utilisation exceed the renewable limits. Water demand for municipal and industrial use is rising fast and exceeds its supply. Better planning, management and rational use could safeguard the sustainability of this scarce resource.

Agricultural productivity, in terms of returns to water and labour, is relatively high but can be further improved. To begin with, irrigation efficiency in the Jordan Valley can be improved. That efficiency is now just 42% in the northern section with a cropping intensity of only 100-120%. Higher productivity would require improved technology and farming methods. The education and training of farmers, and improvements in the delivery of research, extension and other producer services will further facilitate the adoption of improved technology and increase productivity. It is important to make such services more demand-driven and farmer-focused.

Markets for Jordanian agricultural produce also pose problems. Exports have historically been dependent on regional markets. The Gulf markets were traditionally the major outlets for Jordan's horticultural exports. Saudi Arabia, Kuwait, the United Arab Emirates (UAE), Qatar and Bahrain together used to import about 500,000 tons of fresh fruit and vegetables from Jordan. The shares exported to other Arab markets and Europe were 62,000 tons and 6,000 tons respectively. Because of the Gulf War, demand in the Gulf markets has decreased and export prospects thus eroded. Presently, export capability lags behind the production capacity.

The local market, although growing fast, is relatively small and cannot absorb all surplus production. As a result losses increase and the farmers' incomes decrease.

Jordan must divert its export outlets to the relatively stable, fast markets of Western Europe. These markets, however, demand a higher quality and Jordan must therefore improve her produce quality in terms of certification inspections and post-harvest handling and packaging (see also chapter 9). To serve the European market, Jordan must also improve market information and logistics in order to be able to monitor off-season demand, niche markets in Europe, and to respond to them in time.

A study conducted by Harrison and Jabbarin (1991), identified twelve crops in which Jordan has a definite commercial potential: strawberry, grapes, asparagus, melons, green beans, eggplants, tomatoes, peppers, peaches, nectarine, cherry and raspberry. The same study recommended off-season exports through niche market windows targeted at four principal European markets, namely, Germany, France, the United Kingdom, and Switzerland.

Jordanian agriculture faces many problems: technical, institutional, structural, and in terms of government regulations. Current government policies have on the one hand encouraged the rapid growth in production of fruits and vegetables, making it possible for Jordan to satisfy both domestic and export needs. On the other hand, polices governing subsidies on inputs for production stimulation led to an inefficient use of land, water resources and artificial inputs (pesticides, concentrates, fertilisers). The future of the agricultural sector depends largely on its ability to increase efficiency of water use, and also on its success in finding new markets and new cash commodities.

For these reasons, the government embarked upon an adjustment programme in the agricultural sector. Jordanian agriculture must become profitable and efficient in its use of resources. This programme covers improvements in the management of water and land resources, market liberalisation, institutional development and the improvement of farmers' skills.

2.4 Conclusion

The water balance of Jordan is poor. Clean surface and ground water will become more scarce while the amount of sewagewater will increase rapidly. The agricultural sector represents the largest user of water in Jordan one and is, moreover, also the heaviest polluter. Stimulating the agricultural sector to use treated sewagewater exclusively for irrigation purposes could redress Jordan’s very negative water balance. There is international support for such a development. But limiting factors such as the marginality of Jordanian farming, high production level demands for export commodities, consumers unwilling to pay more for their food, and the scant attention paid by scientific organizations to working together with farmers, must first be overcome. The following question is therefore: ‘what is the basis for improving the production efficiency of Jordanian farming and what significance might treated sewagewater have in this process?’

Chapter 3 – Theoretical framework

The agricultural sector and the sector responsible for sewagewater management in Jordan have until now evolved separately. The idea of using treated sewagewater permanently for irrigation in agriculture is quite new for Jordan, and has not really broken through. If treated sewagewater is indeed to become a permanent natural resource for crop production, then both sectors must work together and in such a way as to ensure that all stakeholders in question are able to take each other's needs and demands into account, always, however, within societal limitations.

Both sectors could be described as a nested set of scales of different complexity (Hart, 1980). The agricultural sector, for instance, could be seen as a cluster of farms in a certain region. Farmers manage their respective farms and are dependent upon co-operation with other stakeholders in the region (e.g. other land users, extension and research institutes or NGO's). These stakeholders depend in their turn on government decisions in terms of laws and regulations. Each level refers to different sets of complexity, and none of them can function without the support of other levels. All levels therefore have a mutual need of each other. The same reasoning was followed for the sector producing treated sewagewater. In other words, decision-making about the use of treated sewagewater for irrigation is a question relevant to all decision makers at the four levels of both sectors. So the question as to when, how, and under what conditions, treated sewagewater may be used for crop production concerns each sector as a whole (Bird et al., 1995). This decision-making process is made easier if the agricultural sector and the sector producing treated sewagewater agree on terms of quality for the water supplied.

What working together between the two sectors is intended to mean here is shown in figure 3.1: it means that both sectors engage in dialogue about the requirements of crop production. Crop production is optimal when it supplies the highest number of kilograms per unit of input (e.g. water, energy, fertiliser, money or pesticides). Optimal production gives the best benefit ratio (income minus production costs). It is what the farmer has to strive for and is what the treated sewagewater producer has to make possible. This becomes a reality when the nutrients in water, supplied by the sector producing treated sewagewater, match the nutrient requirements of crop production. When this is the case, the farmer needs not spend on chemical fertilisers while the treated sewagewater producers on their part do not incur increased costs for purification. Working together, then, means that both sectors are in permanent negotiation about what each needs from the other.

Figure 3.1. shows that treated sewagewater for crop production has at least three important consequences. Firstly, there are consequences related to nutrients in treated sewagewater not taken up by crops. Such nutrients are simply lost and pollute the farm and environment at large. Secondly, there are consequences related to pests and diseases attendant upon the intake of treated sewagewater. Thirdly, there are consequences with regard to the quality of marketed commodities. Consumers want to be sure about any health and safety issues involved. Let us consider them in more detail.

Loss of nutrients at crop production level is obvious, as according to Lantinga et al. (1998) only 20 to 30% of supplied nutrients are taken up by crops in mainstream farming systems. Farmers must learn to rely on what is supplied by treated sewagewater, and must also learn how to manage their soils so that these buffer nutrients not taken up by crops. Suppliers of treated sewagewater must learn how to bring the level of nutrients supplied by their water in accordance with what farmers actually need. Managers of treated sewagewater, it is safe to assume, do not want to be blamed for environmental pollution, so they must be absolutely sure that farmers' productions systems are adequately designed in such a way as to ensure that losses are buffered and recycled for the benefit of the next production cycle.

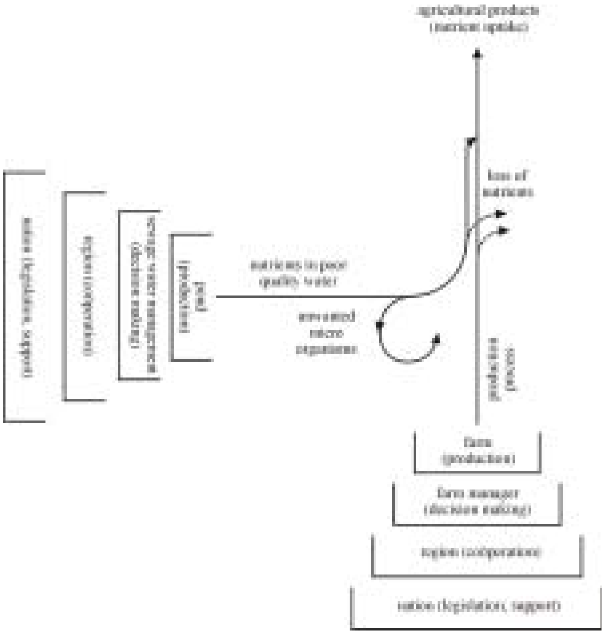


Figure 3.1 Model for co-operation between the treated sewagewater producing and using sectors in Jordan. Both sectors are represented as a set of nested scales on four levels of aggregation. Co-operation occurs where their respective production streams intersect. Three consequences are involved: the loss of nutrients must somehow be buffered by the soil, unwanted micro-organisms (dangerous from a crop protection point of view) must be prevented from entering the farm, and consumers must be informed about the safety of this co-operation.

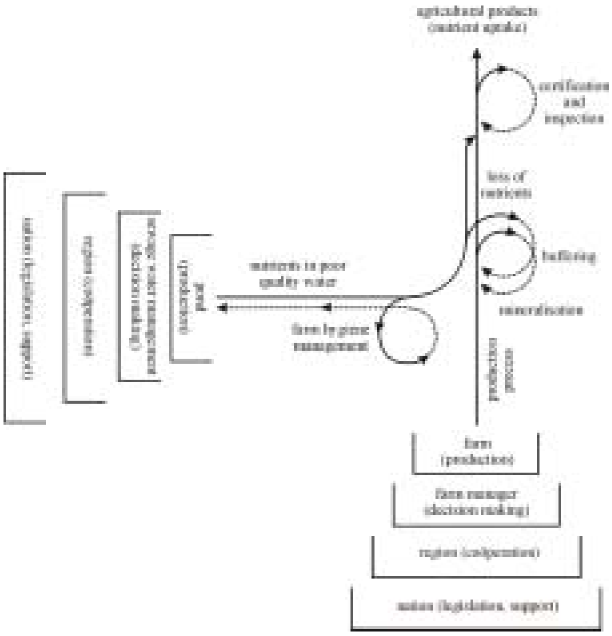


Figure 3.2 Model of the treated sewagewater producing and using sectors as theoretical framework for field research. Farmers must be facilitated in redesigning their farming systems so that nutrient residues are buffered by effective nutrient cycles in the soil, harmful micro organisms can be returned to treated sewagewater producers (crop protection management) and certification and inspection of farm processes become a reality. Field research must focus on these issues.

Harmful organisms, also carried along with treated sewagewater, could thwart the farmer's crop protection management. It is therefore necessary that farmers have working access to sufficient technologies, e.g. monitoring systems and devices for preventing treated sewagewater from entering their farms. Farmers obviously do not want to loose their harvests, nor do they want to be depicted as polluters of society due to heavy use of synthetic pesticides.

The *consumer being the end user* of treated sewagewater and natural resources in the form of farm products wants to be sure that commodities coming from production sites using treated sewagewater are safe. He also wants to be sure that a farm using treated sewagewater does not harm his drinking water and the overall quality of air and soils. Producers must therefore learn to communicate with consumers. According to Woerkom et al. (1998), communication between consumer and producer is best when certified labels on products are used.

It is clear that the farmer must initiate this process of harmonisation. He can do this by redesigning his farm in such a way as to meet criteria of the sector producing treated sewagewater, of consumers and, of course, his own. Figure 3.2 shows that the first points of impact are soil management, disease and/or pest prevention, and certification and inspection, leading to labelled commodities on the market.

Appendix 3.1, 3.2 and 3.3 informs the reader in more detail about the organisation and working methods of the treated sewagewater production sector, quality control of treated sewagewater in practice and organisation and working methods of the agricultural sector.
Quality control of treated sewagewater in practice, and about the organisation and working methods of the agricultural sector.

3.1 Conclusion

The very negative water balance of Jordan is caused among others by inefficient agricultural practices. According to the 'polluter pays' principle the agricultural sector must start improving these practices. Farm improvement has three main goals: improving soil management so that soils gain nutrient-buffering characteristics, preventing infestations of micro-organisms contained in treated sewagewater, and designing a certification system to inform the consumer that the commodity purchased is the result of good agricultural practice. Farm improvement is facilitated by close co-operation between the treated sewagewater producing and using sectors. The respective sectors must negotiate the end terms regarding the quality of treated sewagewater supplied to farms. Co-operation is beneficial to both sectors as both will reduce production costs, contribute to environmental protection, and reduce Jordan's water deficit.

Chapter 4 – Research questions

The question of when and how treated sewagewater can be used for applications in Jordanian agriculture is a matter of land use (see chapter 3). So each aspect, even those not immediately related to treated sewagewater using farms, must be considered as being an integral part of this research. Figure 4.1. summarises the aspects concerned. Each encircled number in the figure refers to one of the aspects, hereafter presented as research questions.

- What area containing farms is suitable for our research (4.1.)?
- How should farmers, being the most important stakeholder in our research, be involved (4.2.)?
- To what extent is treated sewagewater as a fertiliser source suitable for crop production (4.3.)?
- How can, and should, existing farms be redesigned into enterprises dependent upon the nutrients in treated sewagewater (4.4.)?
- What are the strengths and weaknesses of treated sewagewater using farms once these are established in practice (4.5.)?
- What must the government do to stimulate co-operation between treated sewagewater producing and using enterprises so that the designs of farms using treated sewagewater become practicable (4.6.)?

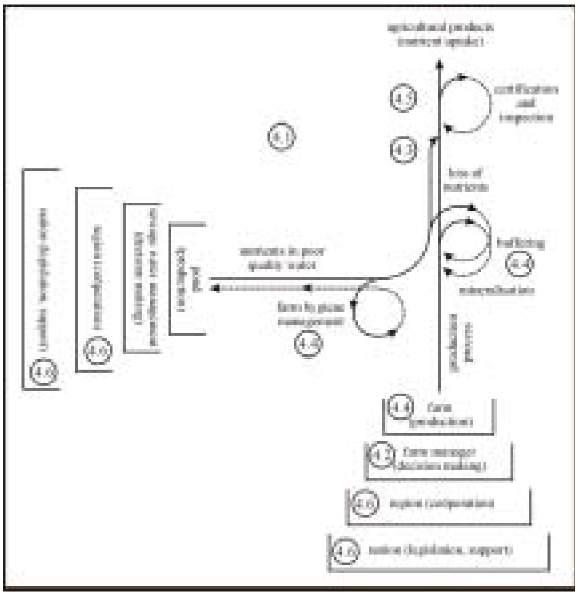


Figure 4.1 The co-operation between the treated sewagewater producing and using sectors are suggested here as a set of activities inside a certain region. Each encircled number refers to one of the research questions that the present project must address. The dotted lines indicate what the project must realise: closing the nutrient cycle inside the farm, making disease management operational and establishing communication with consumers about the safety and quality of the commodities they purchase.

4.1 Identification of the research site and its pilot farms

Farms must be able to take treated sewagewater in as irrigation water. Participating farms must therefore be localised in areas where treated sewagewater can be reached easily and without high costs. Moreover, laws must be taken into account. Jordan does not accept, for instance, farmers making direct use of treated sewagewater in areas close to stabilisation ponds. There are thus areas where the use of locally available treated sewagewater is forbidden in the production of food for direct consumption.

4.2 Relation between farmers and researchers

Jordan does not have a tradition of involving farmers in academic research. But according to Hall (1968), innovation in agriculture is no longer something that happens based on the perception that a service hatch is required between experimental, disciplinary science and farmers. Experiential knowledge, obtained in farmers' everyday and varying reality, is increasingly coming to be seen as essential information. Our project aims at system innovation (Wolfert, 2002): we therefore assume that it cannot do without the participation of farmers and their farms. Complications involved, considering the context of Jordan's current research tradition, must consequently be investigated in advance.

4.3 Suitability of treated sewagewater as nutrient source for crops

It is not yet clear to what extent treated sewagewater can indeed be used as a fertiliser source for crop production. We must therefore determine the composition of treated sewagewater used for farming and also determine the extent to which treated sewagewater meets the nutrient needs of crops.

4.4 Theoretical model of treated sewagewater using farms

Farm improvement is a form of system innovation. The innovation process is essentially a designing process: it transforms an existing and unwanted farming system into a future and required one. The process begins with farmers' demands and ends by providing a theoretical prototype of the farm in question. The theoretical prototype, something like a blue print must further be tested in practice. As Jordanian farmers have hardly any experience with farming systems research it is absolutely essential that the redesigning process occurs with care and respect. This qualification necessitates the application of agro-sociological information as well.

4.5 Strengths and weaknesses of prototypes

As soon as participating farmers have a prototype of their farm at their disposal, that is to say, that they know how to realise the prototype step by step, they also need insight into the strengths and weaknesses of the theoretical concept involved. Stakeholders such as government, retailers or environmental protection organisations could support further development of improved farms by reinforcing its strong aspects and reducing its weak ones. This would also support the dissemination of suggestions for farm improvements.

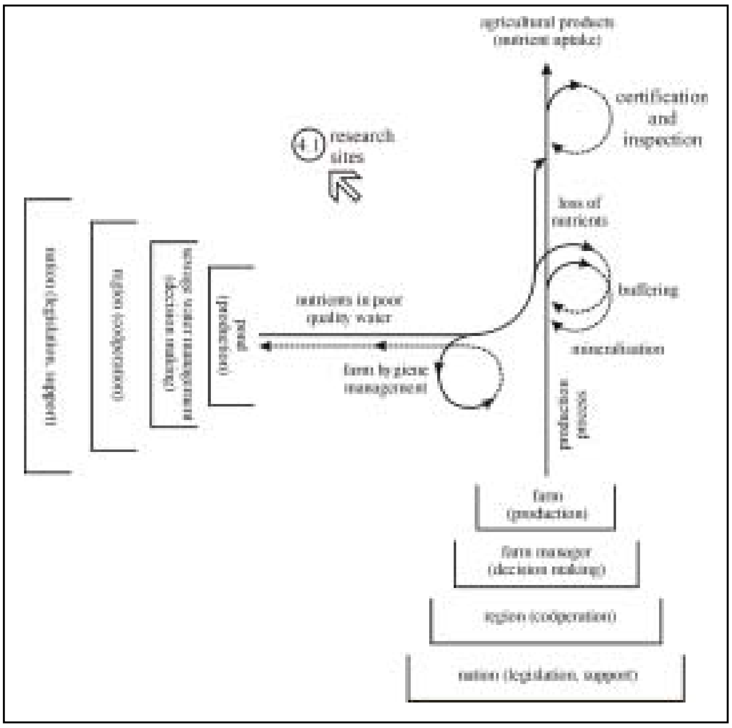
4.6 Support by government policy

The treated sewagewater problem is not a question of farmers alone. It is a question of national or even of international interest. The Jordanian government is, for instance, interested in all possibilities conducive to the reduction of Jordan's water scarcity. In a very real sense, then, using treated sewagewater in farming contributes to the realisation of Jordan's national policy. The research question also addresses, therefore, how the government could stimulate mutual co-operation between the treated sewagewater producing and using sectors. Only when that co-operation becomes a reality, will designs of treated sewagewater using farms contribute effectively to a diminution of Jordan's water scarcity.

4.7 Conclusion

The research questions in our present project are about the identification of a suitable research area, about acquiring insight into the consequences of working with reluctant farmers on their farms, about the question as to how far treated sewagewater may meet crop requirements, about the design of treated sewagewater using theoretical prototypes, about the strengths and weaknesses of treated sewagewater using farms in Jordan, and about the way in which farmers using treated sewagewater could demonstrate the health and safety of their produce to consumers. These issues will be discussed separately in the following chapters.

Chapter 5 – Suitable research sites



What is the best site for conducting research on the creation of farms using treated sewagewater in Jordan? Considering the goals of the WASTEVAL project, the best site is one where:treated sewagewater is readily available to participating farmers;

- participating farmers have a well-functioning irrigation system at their disposal;
- farmers are genuinely interested;
- farmers are willing to co-operate with each other; and
- the farms involved are suitable for the provision of data.

In the experience of agronomic designers, once a number of farmers in a certain region had begun prototyping, other land users in the same region tended to become interested (Fliert, 1993). The best site for our project is therefore also the one where potentially interested parties such as non-governmental organisations, trade and retail organisations, policymakers, and extensionists or consultants could participate. This chapter explains how the most suitable research site was found.

5.1 Objective

There were three objectives:

- identify a suitable research area;
- determine the quality of treated sewagewater involved; and
- identify suitable farmers willing to participate in the present project.

The suitability of a research site depends primarily on the availability of treated sewagewater for use by the farms that function as pilots during the project. The farms in question are pilots until the point at which the farmer begins to manage his production system according to the new rules for primary production making use of treated sewagewater as a fertilisation source. The quality of the treated sewagewater must therefore be ascertained in advance.

As Jordanian farmers are not used to *participation in research processes*, misguided expectations about the project may exist among participating farmers. Farmers must therefore understand that they are not paid for participating, nor do they obtain services or machinery for free. They must understand that they, and they alone, have to do the job, facilitated by researchers. Farmer and facilitator have to work together in such a way that mutual trust forms the basis for a concerted discovery of roads leading to profitable, safe and sustainable farming systems using treated sewagewater.

5.2 Methods

The search for a *suitable research site* was not difficult. There is only one region in Jordan where treated sewagewater is available close to farms: the area between the As Samra sewage treatment plant and the Jordan River. In principle, all farms inside that area have ready access to treated sewagewater of varying quality.

The *quality of available treated sewagewater* was analysed and based on the data obtained we were able to divide the area into three zones. Each zone was characterised by one particular type of sewagewater quality. We subsequently identified the participating pilot farms per zone based on information or advice from:

- scientific colleagues with field experience in the aforementioned area;
- governmental people who knew which farmers had always demonstrated curiosity and innovation oriented attitudes; and
- extensionists working in the identified research area.

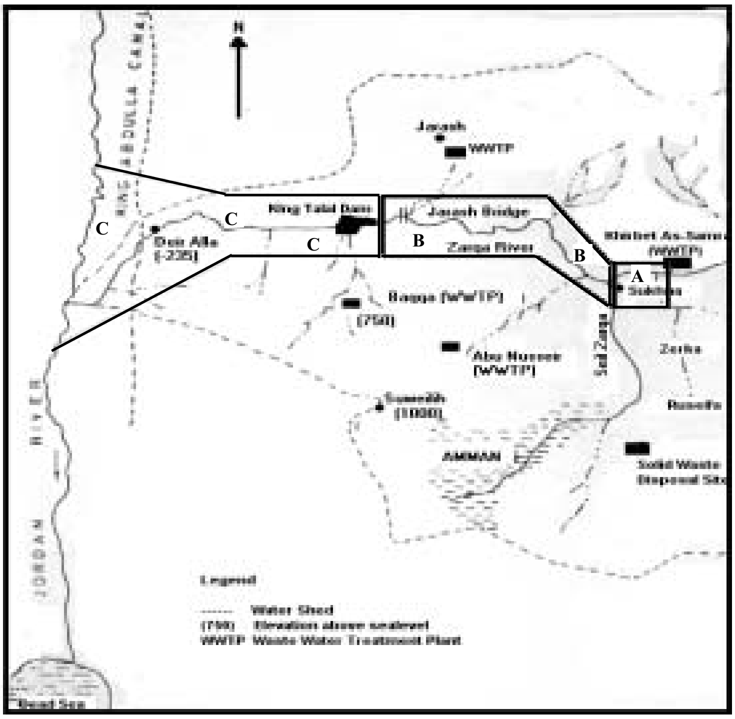
Farmers whose names had emerged in all of the three identification rounds were the individuals visited first. During these visits, I tried to gauge both their willingness to participate and the suitability of their respective farms.

5.3 Results

We found three levels of quality in the treated sewagewater of the area between the As Samra sewage treatment plant and the Jordan River. This was in itself not difficult to assess, as these three quality levels coincide with the three different legislated licenses for primary production.

5.3.1 Three research zones

The area covered by this study is shown in Map 5.1. It is about 50-70 km north of Amman, the capital of Jordan. It extends from the Khirbet As Samra Treatment Plant, Hashmiya, As Sokhna, and the farms along the banks of the Zarqa River to the King Talal Dam (KTD), as well as the lands from the KTD to include the middle of the Jordan Valley. It may be noted that the lands covered by the study, including such installations as the As Samara and the KTD, all make use of the Zarqa River system



Map 5.1 The study area has been indicated by the solid straight lines, all forming the three zones A, B and C. Each zone is coterminous with the particular quality of treated sewagewater available in that zone.

The study area encompasses varied terrain. Most of the area consists of a plateau undulating between 500-1000 m in altitude. The valley of the Jordan River, however, marking the western boundary of the study area, has an altitude ranging between 0-400 m below sea level.

The average annual rainfall ranges from about 500 millimetres in the hills to 155 millimetres in the extreme east of the study area. In the remaining areas (Deir Alla) it averages mainly about 380 millimetres. There is a large area of indigenous forest in the northwest of the study area, which is designated as a forest reserve and managed by the Ministry of Agriculture and Department of Forestation and Forestry.

The three zones also possess specific characteristics based on natural resources, population density, type of farming and other economic activities. The main characteristics of these zones are:

- zone A: This zone lies in the eastern part of the study area, constituting about 14% of the total area under study. It includes the Khirbet As Samra treatment plant, Hashmiya, and As Sokhna to the point where the Zarqa River converges with water coming from the Khirbet As Samra treatment plant. Flat land, which is in poor condition, dominates most of this zone. Furthermore, most of the large-scale industries are located in this zone. Petroleum Refineries and Thermal Electrical Power installations, forming the largest industries, are located in the middle part of this area, while smaller factories and industries, especially poultry farms, are scattered along the edges of the Zarqa River. The soil in this zone is not shallow but sandy in the eastern part. Cultivated land in this zone is usually planted with lettuce, radish, cauliflower and alfalfa.
- zone B: This is the largest zone, comprising some 41% of the study area. It lies in the middle of the study area and is characterised by steep slopes with shallow soils. The zone contains few areas of natural forest, especially in its western part, which is close to Jerash Bridge and the KTD. It contains a number of orchards, however, vegetables irrigated by well water grow on the banks of the Zarqa River. Livestock are also raised in this zone. Industrial establishments are absent. Most of the land in this zone is not cultivated, although it has the potential for cultivation.
- zone C: This zone lies in the western part of the study area. It extends from the KTD down to the Middle of the Jordan Valley. Steep slopes and mountains characterise the eastern part of the zone, whereas the western part is mainly flat with thick soil layers. Due to the richness of the land, most of it is under cultivation. Olive trees dominate the eastern part of the zone, while citrus trees and vegetables dominate the western part. Goat-raising is found in this area.

5.3.2 Water quality in the zones

The Khirbet As Samra treatment plant is the largest and most significant plant for irrigated agriculture. Background information pertaining to the plant and its existing use is provided first. The treated sewagewater quality is discussed and assessed with respect to World Health Organisation (WHO) and Food and Agriculture Organisation (FAO) guidelines at the discharge point and at several sites downstream after dilution.

As Samra treatment plant

The Khirbet As Samra treatment plant, located some 40 km northeast of Amman, is the largest plant in the country, handling sewagewater from Jordan's two major cities Amman and Zarqa. It consists of three parallel treatment series, each composed of two anaerobic ponds, four facultative and four maturation ponds, occupying about 181 hectares. The ponds, originally designed to receive an average influent of 68,000 m^3/day (PRIDE project, 1992), are overloaded and receive an average of 169,000 m^3/day (RSS, 2000). The overloading of rated capacity by nearly 60% is adversely affecting the ponds' performance, and hence the effluent quality discharged into the Zarqa River and the KTD, and threatens to pollute ground water aquifers.

Zarqa River Basin

The Zarqa River Basin is considered to be the most complex resource system in Jordan. The Basin includes three of Jordan's largest cities and contains about three-fourths of the national population. Land uses include urban development, military installation, forests, industrial complexes, and farmlands with both irrigated and rain-fed agriculture. This Basin represents the main catchment area of the KTD.

A small portion of the treated sewagewater discharged from the Khirbet As Samra treatment plant is used for on-site irrigation of fodder and a variety of trees. However, over 147,803 m^3/day (RSS, 2000) is discharged into Wadi Dhuleil, a tributary of the Zarqa River, which flows to the KTD. The dilution of the treated sewagewater in the Wadi is negligible, as the latter is dry for most of the year (Cairncross, 1987). The mean base flow of the Zarqa River just upstream of the confluence is less than the flow of the treated sewagewater. By the time the river reaches Jerash Bridge, 41 km downstream of Khirbet As Samra, it has a base flow of 86,400-129,600 m^3 / day. This, however, may fall to 43,200 m^3 / day in dry years (Cairncross, 1987). Treated sewagewater from the Jerash treatment plant discharged into Wadi Jerash flows into the Zarqa River at Jerash Bridge. Upstream of Jerash Bridge, the surface water containing treated sewagewater is used for the restricted irrigation (fodder and trees) of a few hundred hectares. In addition, a series of wells has been drilled beside the river and is used to irrigate 120 hectares of vegetables. Downstream of the bridge, water is pumped from the river to irrigate vegetables eaten cooked.

Treated sewagewater discharged by the Abu Nusier and Baq'a treatment plants eventually reaches the KTD through two tributaries of the Zarqa River, namely, Wadi Addananeer and Rumeimeen. The Khirbet As Samra treatment plant, though, remains the major source of treated sewagewater, contributing about 79% of the total water volume received by the KTD in 1999 (Table 5.1). This value, however, does not reflect losses due to seepage, evaporation and irrigation, which are estimated at 9.6 million m^3 per year (RSS, 2000). Other sources of inflow to the KTD include springs in the Zarqa River area, irrigation return flows and industrial discharge estimated at 6500 m^3 / day (Ghur and Al Salem, 1992). Industrial discharges are considered the greatest source of KTD pollution.

Table 5.1 Yearly inflow and outflow of King Talal Dam and As Samra Treatment Plant share (1990-1999).

Year	Inflow (MCM/Yr)	Outflow (MCM/Yr)	Volume of water in KTD (MCM)*	As Samra effluent (MCM/Yr)
1990	60.81	75.7	6.2	29.6
1991	92.9	52.2	40.4	30.3
1992	221.9	207.4	60.5	39.4
1993	108.8	130.6	38.9	40.0
1994	112.7	84.7	60.3	40.6
1995	80.2	100.8	39.9	43.9
1996	81.8	85.9	35.7	46.6
1997	102.1	83.2	54.7	47.8
1998	73.0	96.0	31.7	54.5
1999	67.1	88.9	9.9	52.9

Source: RSS, 2000

** Volume of water in the King Talal Dam at the end of December.*

King Talal Dam (KTD)

The KTD is a medium-size earthen dam located 35 km to the northwest of the capital Amman. The KTD was commissioned in the late seventies, designed to hold about 60 million m^3 of water to be used as potable water during the dry season. Its capacity was expanded to 82 million m^3 in the mid eighties due to the shortage of irrigation water in the Jordan Valley resulting from integrated development plans in the valley. It lies on the Zarqa River and is fed by several small tributaries. Its water is derived from four main sources, rainwater runoff, spring water, treated sewagewater from the Khirbet As Samra treatment plant and treated and untreated industrial sewagewater which discharges directly into the Zarqa River.

Rapid population growth, industry and agriculture started in the early seventies and has continued up to the present time. This has resulted in a large concentration of population in the Amman-Zarqa region, and small, medium and large industries alongside the Zarqa River. Sewagewater of domestic and industrial treatment plants polluted the main supply tributary of the KTD. This situation led to an adjustment of the objectives of the KTD, which is now used to supply water for irrigation in the Jordan Valley rather than providing potable water, as was originally planned. The pollution threat to the Zarqa River and the KTD fluctuates, as treated sewagewater from the Khirbet As Samra treatment plant mixes with the natural flow of the river reaching the dam. This fluctuation reflects the volume of treated sewagewater flow from the treatment plant, the volume of water flow in the Zarqa River, and finally the mix of water discharged from the KTD to irrigate crops in the Jordan Valley. The threat is most acute when water discharged from the KTD consists predominantly of the treated sewagewater of the Khirbet As Samra treatment plant, which usually occurs during the summer and fall seasons. The fluctuation of pollutant content in the KTD poses a water quality problem as well as a management problem. If badly handled, it constitutes a threat to crops grown in the Jordan Valley.

Jordan Valley

Water stored in the KTD is released for unrestricted irrigation in the Jordan Valley. During dry seasons, the Zarqa River water flowing into the KTD becomes essentially treated sewagewater (Table 5.1). Presently, about 1,100 hectares are irrigated in the Jordan Valley using KTD water alone, and an additional 8,900 hectares using KTD releases after entering the King Abdullah Canal (KAC) (Taha, 1993). There have been complaints about the quality of this water for irrigation since treated sewagewater started to reach the KTD in 1985. Records show that Electrical Conductivity (EC_w) of KTD water started to increase steadily since then. Organic pollution and faecal coliform contamination is increasing. Various studies have confirmed that the KTD is in a hypertrophic condition. Masses of algae bloom occur every spring and during most of the warm months of the year. The KTD thermally stratifies during the summer period from March or April each year. Royal Scientific Society (RSS) records on the KTD show that the water quality of the bottom layer is not much different from the surface. However, the risk of anaerobic conditions arising in the lower layer is likely to increase progressively in the future, and would have adverse effects on crops if it contained phytotoxins (Cairncross, 1987).

KTD water is discharged from the bottom of the dam, from where it flows in an open stream to a point 17 km downstream of the outlet, where a diversion weir impounds the water. Part of the water is subsequently distributed through a closed pipe network for unrestricted irrigation in the Zarqa Triangle Project. The remainder is diverted to a canal that meets the KAC near Mu’addi. The Total Dissolved Solids (TDS) value of KTD water, from the outlet to the point of redistribution, is increasing. Saline springs and seeps reportedly contribute to the degradation of water quality and may limit the usefulness of the water.

5.3.3 Farms and farmers in the zones

Pilot farmers were identified during personal visits and discussions held with them. I explained to them why I had come and how I had obtained their addresses. Many farmers did not trust me and sent me away. Others became interested and raised their own questions. Sometimes they started to complain about their present situation or voiced their thoughts concerning the future of their farms. Both these types of discussion were potentially of great interest to me. They focused on the farmer's own opinions concerning his managerial skills, his agricultural knowledge network, his success in marketing, and his ideas about the quality of life in general. After talks I asked the farmer to show me his farm. I observed his crops and/or animals and irrigation system, and obtained an impression about his soil (quality and physical condition). I assessed the quality of the farm as a whole: is it clean, tidy, hygienic, beautiful (biodiversity) or well organised? Although initially having tried to systemise the selection process concerning farmers-of-interest for participation in my research, I quickly perceived the impossibility of doing so. Instead, therefore, my selection of participating farmers happened quite intuitively.

As a consequence, I also decided to find out how farmers think about research and extension. Indeed, in this respect I observed a spectrum of opinion ranging from reasonable scepticism to distrust and even sincere anger at the influence of formal sciences on the future of the farm. This is fully in line with the observations of many other scientists (Hamilton, 1995; Mettrick, 1993). This result had therefore to be taken into account once I started the research process. A careful and empathetic attitude on the part of the facilitator had to be in operation right from the beginning of the project. This attitude manifested itself by spending considerable time on the introduction of the project's scope and by showing the farmers where in the process they play their role. The scope of the project, presented in the form of a simple flow diagram of activities running for the duration of the project (see chapter 6), was designed and shown during all sessions and meetings with farmers.

The pilot farms finally selected for participation in the project met the following criteria (Kabourakis, 1996):

- sufficient farm size, ≥ 1 ha (average farm holdings in Jordan are characterised by their small size);
- pilot farms are surrounded by other farms having the same environmental conditions and farming system;
- other farmers in the region know the pilot farmer;
- the pilot farmer agrees on the use of his farm as an experimental site; and
- pilot farmers have the realistic possibility of replacing chemical fertilisers with organic ones present in treated sewagewater and manure.

The final number of farmers that were successfully persuaded to participate in the project was small (Table 5.2).

Table 5.2 Farmers visited and those who finally agreed to participation in the study area

Zone	Number of farmers potentially suitable for participation	Number of actually participating farmers
A	15	1
B	36	2
C	53	3

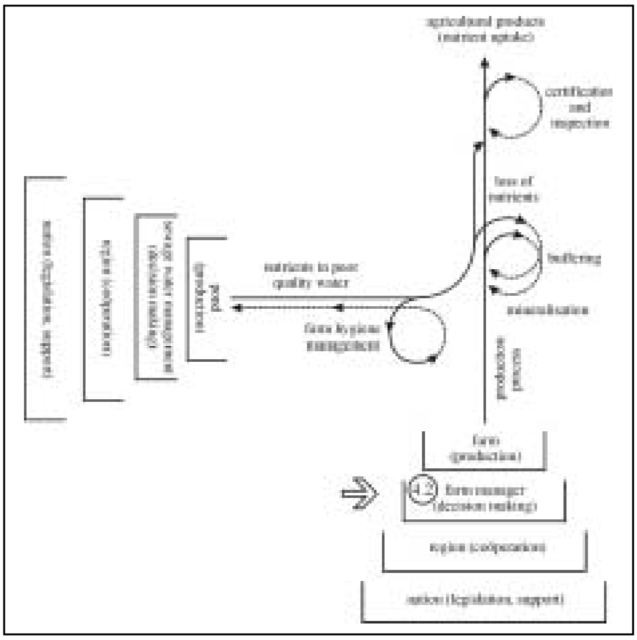
The curiosity of non-participants was, nevertheless, not any less for their being so. In many cases it was a matter of 'lack of nerve' and an extreme dependence on third parties. Participants could be described as innovators with a feeling for research, co-operation and a self-motivating urge to learn.

5.4 Conclusion

The selected study area is suitable for our research. It has sufficient conditions for the collection of reliable information on how farmers could use treated sewagewater for plant production. The area has three zones based on three different levels of treated sewagewater quality. Pilot farms were identified in each of the three zones. That means that the pilot farms in question also work with three different qualities of treated sewagewater. The pilot farmers in the three zones were willing to co-operate on my terms, namely, participation for the duration of the research, prepared to attend regular meetings with colleagues and researchers, and willing to provide data for publication. Table 5.2 shows how many farmers were visited and finally agreed to participation.

A significant complication was the serious perceptual gap between what scientists see as farmers' problems and what farmers themselves see as their problems. By considering farmers as sources of experiential knowledge, rather than empty buckets that must be filled with experimental knowledge derived from controlled experiments in labs or on conditioned fields, I fully expected that such gaps could be successfully bridged. Hamilton (1995) discovered that farmers involved in a project are especially co-operative when they acquire a positive impression of the project's stated aims and activities prior to its commencement. It is important that farmers know when and why their contribution(s) at any given moment is necessary to the project. The overall impression generated by the project, then, has to be formulated in accessible terms and continuously conveyed to the farmers (see Chapter 6).

Chapter 6 – Farmers as designers of their own farms



Involving farmers in research in developing countries is not easy (Mettrick, 1993). The farmers and scientists in question raise many objections. From all my interviews I found, for example, farmers who had in the past made themselves dependent on extension organisations and consequently lost their self-reliance. They came to rely exclusively on information from extensionists: information very much informed by experimental science. There were, subsequently, farmers who became disappointed because scientific information did not work when applied in practice on their farms (Woodhill, 1992). A number of farmers concomitantly became reluctant with regard to banks, insurance companies and even governmental advice, all working on the basis of at times dysfunctional data. I also met farmers who made ‘inventions’ on their own, and within their farms, and did not like to discuss these with potential competitors. Moreover, farmers have their pride too. They are not docile. Their farm is the result of hard and solitary work over many years. In their struggle for life, they developed a range of activities that are not always covered by, or otherwise in compliance with, government rules and regulations.
It is therefore clear that Jordanian scientists cannot address farmers without something more than is currently the case. If this is, moreover, indeed the case, then the researcher hardly knows whether the data he obtains is correct. All answers given in such settings are probably linked to what farmers like to show about themselves. This is exactly what bothers scientists when they start working with farmers: can they (the scientists) accept the data as reliable, accurate and relevant?

The present project touched upon the issue just described. We had to find out how co-operation between pilot farmers and the project’s scientists could be organised effectively in the area between the As Samra treatment plant and the Jordan River. This particular problem implies two basic questions:

- how should Jordanian farmers best be addressed when scientists seek to involve them in the present project? and
- how is the data obtained from participating farmers to be validated?

6.1 Methods

The first question was investigated by means of desk research. We looked for cases where the quality of co-operation between researchers and farmers was crucial. We selected cases from different countries. Criteria were:

- in how far is the particular case relevant to the situation of Jordanian farmers;
- what were the researchers' attitudes with respect to the farmers involved;
- was there support from government or other stakeholders; and
- in how far was the success of a case related to certain forms of co-operation between researcher and farmer?

The second question was investigated in the field. Based on the results obtained from this desk research Jordanian farmers, potentially willing to participate in the project were visited. Open interviews were held and the results checked during farmer-guided field visits. I opted for open interviews in order to prevent socially desirable answers (answers that deliberately promote how farmers would like themselves to be seen by others). So it was not just about the accuracy of the answers given, but also about checking an individual farmer's attitude with regard to the scientist. It was also about trust. By showing interest and by going further into the matter I demonstrated to the farmer that the project really was for his benefit. I had to show him that no hidden agenda was involved and that success of the project was fully dependent upon his attitude and involvement.

6.2 Results

The desk research provided essential learning points for the creation of effective co-operation between farmers and facilitators. This insight helped in the preparation of meetings with farmers. We were thus able to obtain insight into attitudes that would be operative during the project.

6.2.1 Learning from desk research

In my search for relevant literature I was impressed by what had been done so far on farming systems research. This is a type of research in which the farmer and his farm play the central role throughout the process of system innovation. Hardly any of this information appeared to be available in the Middle East. Most of the projects carried out so far in the Middle East refer to hard data and reductionist, or strictly linear, evidence-based research.

I made a selection from all cases studied in the literature. I selected the ones with clear and convincing results (Table 6.1). That is to say, the results of a case of interest must demonstrate a strong relation between farmers involved and project results. The selected cases were subsequently studied in depth.

Table 6.1 Relevant literature on farming systems research

Country	**Subject**	**Author**	**Results**
Indonesia	Integrated pest management in rice	Kenmore (1991)	Yields increased by 15% and pesticide use dropped by 40% among IPM trained farmers
Europe	Introduction of integrated and organic farming	Vereijken (1992)	High production levels among trained farmers despite reduced levels of agro-chemicals
Australia	Land care	Campbell (1994)	Land degradation stopped among trained land users
Brazil	Blackbirds in rice	Da Silva (1999)	Blackbird population decreased among trained rice producers, processors and traders

The study exposed four previously hidden areas of conflict between disciplinary scientists and experience-oriented system researchers:

- hard (experimental) data is more reliable than working with soft (experiential) data;
- conditioned experiments on experimental fields yield better information than farming systems research;
- quantified objectives lead to reliable results as compared with research focused on (learning) processes; and
- modeling improves agricultural sciences more quickly than agronomic designing.

The tension between each approach could be resolved by accepting that hard (experimental) sciences and soft (process-oriented) sciences (e.g. agro-sociology, economy, extension) have two different objectives. The former seeks to explain phenomena through the formulation of basic natural laws. Once these are known, we can use them for the benefit of mankind. The latter seeks to create new things. It aims to develop new technologies, processes or recipes, and thereby improve the quality of life (van den Kroonenberg, 1992). In Jordan most agricultural sciences are based on hard, experimental sciences. The training of farmers as a tool for problem solving is quite new. Table 6.2 shows how the roles of scientists and farmers emerge depending on how the farm is viewed as an object of research.

Table 6.2 The roles of scientists and farmers change as their view on the farm as an object of study changes.

	Disciplinary, positivistic research	**Farming System Research**	**Participatory Research**	**Facilitation research**	
SCIENTIST ORIENTED	←			→	**FARMER ORIENTED**
	Researcher leads and needs profound disciplinary knowledge	Researcher leads and needs communication skills as well	Researcher and farmer work together and need each other's insights	Researcher facilitates on farm experiments and empirical learning	
	Farming systems form an objectified field of study	Farming systems form the ultimate field of application	A farm is a set of nested levels of aggregation	A farm is part of a wider social network within the farmer's world	
	Farmer learns from extension	Farmer learns from demonstration projects	Farmer learns by doing	Farmer acts as a researcher and learns from management failures (heuristically)	

For co-operation with pilot farmers in the area between the As Samra treatment plant and the Jordan River, then, it is necessary that farmers are trained in conducting observations on their own farms. The researchers working in the project must learn to observe in the same way. Desk research taught us that the following criteria are important:

- create a complete overview of the research process spanning the entire project period;
- include in this overview a clear point at which farmers will have to formulate their goals and priorities;
- indicate to the farmers that at a given pont in the process, there will come a time when they, and they alone, will be expected to provide ideas for solutions. This means that farmers will focus their thoughts right from the beginning of the project;
- indicate that at a given point possible solutions for problems will be tried out on their farms; and
- indicate the point in the process at which researchers will start to measure, weigh or count the results.

We designed our research process as follows (Figure 6.1):

- Step 1 presents the 'big picture' of the problem to be addressed. This helps farmers retain an overall perspective.

- Step 2 brings together, identifies and prioritises farmers' problems and opportunities with regard to wastewater use. Opportunities will emerge when identified problems are prioritised (Kolb, 1984), thereby also identifying any modifications required within the 'big picture' (Kelly, 1970; Bawden & Ison, 1992).
- Step 3 gathers together various theoretical solutions from the farmers' points of view. Farmers are important here, as they have to contribute ideas and suggest practical solutions.
- For purposes of agronomic research, it is possible to envisage step 4 as having to do with the implementation of possible solutions in practice. Again, participation by farmers is very important here (Biggs, 1989). A theoretical prototype for the farm is the result of this step.
- Step 5 concerns the scientist's role. The researcher takes the lead here, but collects data in such a way as to ensure farmer participation. Prototypes are tested in practice.
- Step 6 is the joint interpretation of data, and extrapolating and drawing out relevant concepts. Processes that bring farmers and scientists together enable meaningful trials to be established on mutual terms. This stage is consistent with the learning theory of Kolb (1984).
- Step 7 is about the evaluation of the acquired result: the redesigned pilot farm using treated sewagewater. The farmer may decide to proceed further on his own, or may decide to participate in a second round with the scientist in order to improve results or to gain more experience in the art of improving farm structure and management.

The research process, presented as a routing planner throughout the whole project, gave the farmers confidence that their information, data and attitudes contributed considerably to their own success.

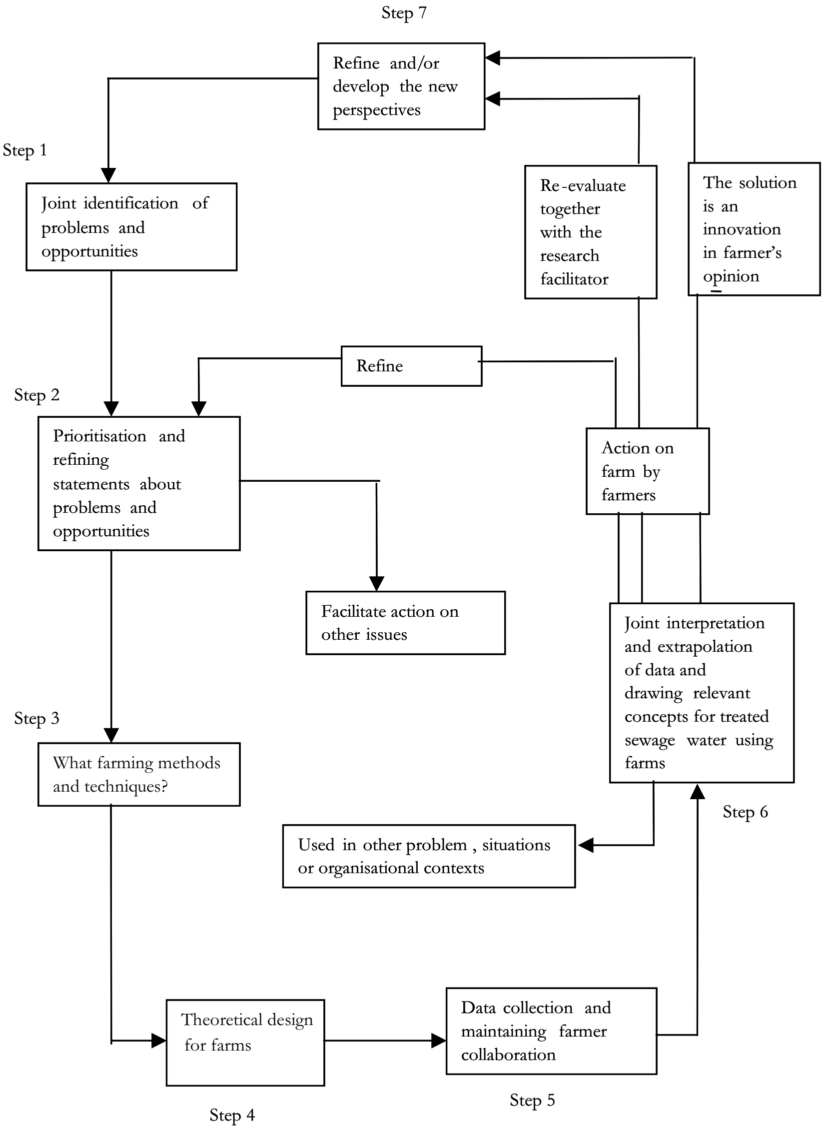


Figure 6.1. A conceptual model for treated sewagewater use in irrigation

6.2.2 Collective decision-making

Working collectively on new farm structures requires rules about what data will or will not be used. The decision-making process concerned must lead to the acquisition of data that will be used by everybody. Röling (1994b) suggested a structure for regional co-operation. He introduced the so-called 'regional platform.' This has the following characteristics:

- platforms are ad-hoc meetings, elected committees, formally appointed boards or councils. It is important that platform members are really representing key stakeholders. They must be able to communicate in an effective way;
- platforms focus on social processes (e.g. conflict prevention, negotiation, institutional development, leadership, power, etc.). From Australian experiences (Campell, 1994;

Hamilton, 1995) it is clear that collective learning becomes more effective when the function of agro-ecosystems is the subject of discussion; and

- finally, the change required may be entirely at the higher system level. This happens when stakeholders, with different and often conflicting interests, find that they need to scale up their decision-making to the higher system level (e.g. by sharing in problem definitions, accommodating multiple perspectives, and negotiating collective management decisions at the higher level). It is in such situations that we talk about a platform for resource use negotiation (Röling, 1994a, Röling, 1994b).

Figure 6.2 presents the decision platform that we operated in this project. The model is according to Vereiken (1995).

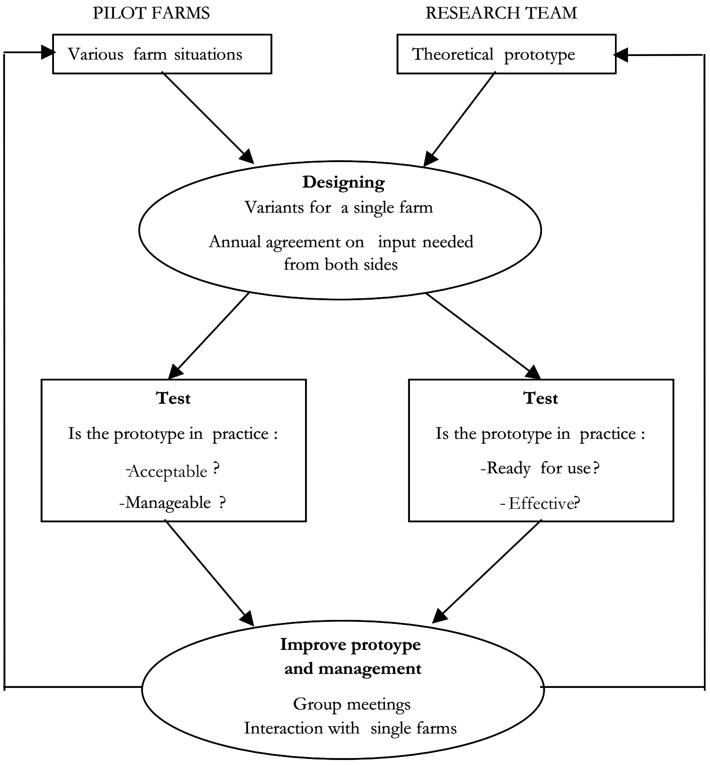


Figure 6.2 Interactive prototyping: designing, testing and improving a prototype by interaction of pilot farms and research team (Vereijken, 1995). The figure makes clear that each group of partners in the project have their own assignments. Their results, however, are synthesised at farmers-researchers meetings

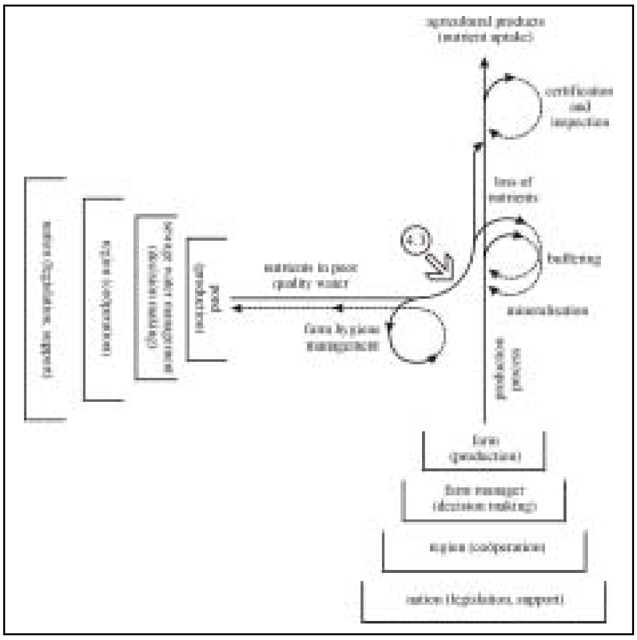
6.3 Conclusion

Jordanian farmers are best met by involving them in a regional platform where researcher and farmer learn to work together. The platform thus functions as a school where farmers are trained in becoming better observers and managers of their land, and researchers are trained in relying on farmers' experiences. Such experiences must be validated by literature, 'institutional' experiments and close observations on pilot farms. Discussions among farmers are also important as a kind of validation.

We established a scheme of steps that farmers and researchers would have to go through during the whole research process. We found that farmers accepted the scheme and felt comfortable about the fact that they were accorded a clear place in the process.

The small number of participating farmers indicates a lack of trust on the part of the farmers visited. Indeed, most of the potentially suitable farmers in the three zones expressed their scepticism about the project, due to their disappointments with research results and institutional attitudes. The platform for regional decision-making must help in overcoming farmers' scepticism during the project process.

Chapter 7 – Suitability of treated sewagewater as nutrient source for crops



Is treated sewagewater suitable for crop production? This question should be addressed by research on treated sewagewater in each of the three zones between the As Samra treatment plant and the Jordan River. Answers must inform pilot farmers about the risks they could encounter: risks concerning their harvests and risks concerning the long term effects of treated sewagewater supply on their production sites. There are three sub-questions involved:

- the quality of treated sewagewater in the project area as a whole;
- the potentials of treated sewagewater for manuring purposes and
- possible side effects of treated sewagewater for irrigation on farmland.

7.1 Suitability of treated sewagewater for irrigation

Table 7.1 summarises the average values of water quality parameters (RSS, 1999 and 2000), most relevant to agricultural use, during the irrigation period in summer 1999 and winter 2000. Table 7.12 gives a further overview of water quality parameters of the study region, but for the year 1998-1999. The variability of key parameters is discussed later. Although winter irrigation is practiced in the Jordan Valley, it is believed that, except for dry years, water quality during that period is more critical for irrigation. Monthly variations of all parameter values are expected. However, deviations from the average would not be sufficient to push the water quality into a different category of use. Hence, the average values shown in Royal Scientific Society (RSS) records are deemed to be adequate for the general purpose of determining the suitability of treated sewagewater at sites 4 and 5 (zone A), 5.1 and 7 (zone B), 100 representing the inlet of the KTD and 600 (zone C) for irrigation (see Map 7.1 and 5.1, and paragraph 5.3.1).

Table 7.1 Water quality of As Samra effluent and selected sites along the Zarqa River during the irrigation period in summer 1999 and winter 2000.

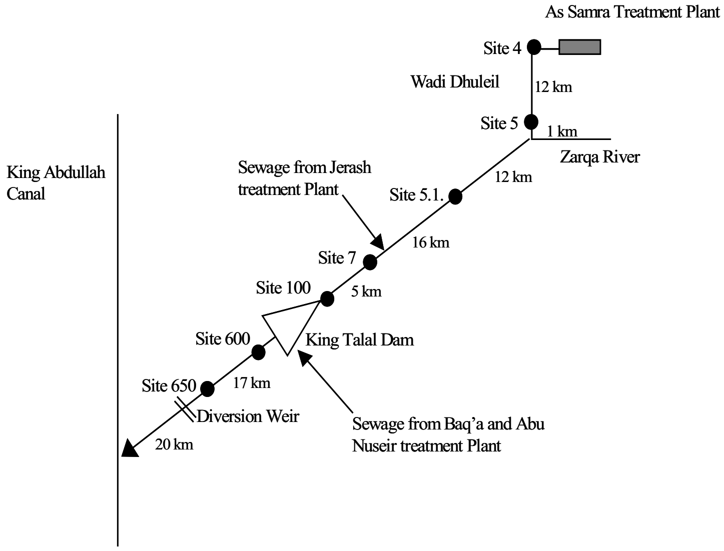
Parameters	Unite	Average during the irrigation period					
		Site 4[a] Fodder [c]	Site 5[a] Fodder	Site 5.1a trees	Site 7[a] trees	Site 100[b] KTD inlet	Site 600[b] Vegetables
Electrical Conductivity (EC_w)	dS/m	2.5	2.5	2.5	2.5	2.7	2.4
Total Dissolved Solid (TDS)	mg/l	1253	1260	1335	1206	1481	1314
Sodium Adsorption Ratio (SAR)		5.8	-	-	-	5.7	4.7
Sodium (Na)	mg/l	252.9	-	-	-	301.2	250.6
Chloride (Cl)	mg/l	382.9	-	-	-	475.0	404.1
Boron (B)	mg/l	0.7	0.7	0.7	0.5	0.7	0.6
Ammonium (NH4-N)	mg/l	61	58	47	25	43	21
Nitrate Nitrogen (NO3-N)	mg/l	23.6	17.9	17.4	-	8.3	2.9
Total Nitrogen (T-N)	mg/l	81	-	-	-	61.7	28.2
Total Phosphorus (T-P)	mg/l	19.4	-	-	-	13	6.8
Bicarbonate (HCO3)	mg/l	785	-	-	-	9.7	9.4
pH		7.8	8.0	7.9	7.9	8.1	7.8
Total Suspended Solid (TSS)	mg/l	122	108	117	32	85	10
Total Faecal Coliform Count (TFCC)	MPN/100ml	1.0E^{+04}	1.2E^{+04}	0.6E^{+04}	1.2E^{+04}	0.3E^{+04}	0.03E^{+04}
Intestinal Nematodes	Eggs/l	0	-	-	-	0	0

[a] RSS, 1999

[b] RSS, 2000

c Most popular crop grown in each zone

For site location refer to Map 7.1



Map 7.1 Schematic lay out of sampling sites for As Samra effluent, the Zarqa River and the King Talal Dam

Water Electrical Conductivity (EC_w) and Total Dissolved Solid (TDS)

The quality of treated sewagewater with respect to EC_w (a measure of water salinity) and TDS represent a Slight to Moderate Restriction (SMR) on use at all sites. Assuming that irrigation water is the only source of salt, the long-term influence of continuous irrigation with the given water quality at any zone can be predicted using the equation

$$EC_e = X * EC_w \text{ (FAO,1985)} \qquad \text{eq. 1}$$

where,

EC_e = soil salinity, dS/m

EC_w = salinity of the applied water, dS/m and

X = concentration factor

Assuming a 40 – 30 – 20 - 10% crop water use pattern from the upper to lower quarter of the rooting depth and a 15% leaching fraction, with a concentration factor of 1.5, table 7.2 shows the expected soil salinity resulting from the irrigation water salinity of all sites. The corresponding crops' relative yield can be calculated using the following equation

$$Y_r = 100 - B\,(K_e - A) \text{ (Mass,1984)} \qquad \text{eq. 2}$$

where,

Y_r = relative yield.

B = the percent yield decrease per unit salinity increase above the soil salinity threshold.

K_e = EC of an extract of a saturated soil paste, which is equivalent to EC_e (a measure of soil salinity), dS/m, and

A = the soil salinity threshold i.e. the maximum allowable salinity without yield reduction below that for non-saline conditions.

Table 7.2 Suitability of As Samra effluent and Zarqa River water for irrigation using EC_w and TDS.

Effect	Sampling sites					
	Site 4	Site 5	Site 5.1	Site 7	Site 100	Site 600
A. Degree of restriction on use:						
EC_w	SMR*	SMR	SMR	SMR	SMR	SMR
TDS	SMR	SMR	SMR	SMR	SMR	SMR
B. Long term effect on soil salinity: EC_e, dS/m	3.8	3.8	3.8	3.8	4.1	3.6

* Slight to Moderate Restriction on use

For site location refer to Map 7.1

Based on A and B values presented in Appendix 7.1 relative yields of all crops known to the study area, given the water quality in each site and a leaching fraction of 15%, are shown in table 7.3. In order to obtain a tolerant degree of yield loss, not exceeding the level recommended by FAO at 10%, salt removal by leaching is necessary.

Table 7.3 Long term influence of EC_w on crop productivity using As Samra effluent and Zarqa River water

Crop type	Relative Yield,%					
	Site 4	Site 5	Site 5.1	Site 7	Site 100	Site 600
Sweet Corn	74.7	75	74.3	75.4	71.8	77
Barley	100	100	100	100	100	100
Alfalfa	86.8	87.0	86.6	87.2	85	88.2
Citrus	67.6	68.1	67.2	68.6	63.8	70.7
Apricots	49.1	49.9	48.5	50.6	43.7	53.5
Grape	78.1	78.3	77.8	78.6	75.8	79.9
Tomato	87	87.3	86.7	87.6	84.7	88.9
Cucumber	83	83.4	82.6	83.8	79.9	85.4
Pepper	67.4	67.9	67	68.3	64.1	70.1
Beans	46.9	47.5	46.3	48	42.4	50.5
Cabbage	80.5	80.8	80.2	81.1	78.2	82.4
Potatoes	74.7	75	74.3	75.4	71.8	77
Onion	58	58.5	57.5	59	54.1	61
Lettuce	67.4	67.8	67	68.2	64.3	69.8
Spinach	86.2	86.5	86	86.7	84.4	87.7
Radish	66.1	66.5	65.7	66.9	63	68.5
Carrots	60.4	60.8	60	61.2	57	63.1
Strawberry	-	-	-	-	-	12.8

Notes:

- blank space indicates that crop is not presently cultivated in that area
- crop yield reductions are assumed to result from salts in the irrigation water only.
- assumed leaching fraction =15%.
- assumed crop water use pattern: 40-30-20-10% from the upper to the lower quarter of the rooting depth.
- $EC_e = 1.5*EC_w$ (Table 7.2)
- for site location refer to Map 7.1

The minimum leaching requirement needed to maintain the targeted yield is estimated as follows:

$$LR = \frac{EC_w}{5EC_e - EC_w} \text{ (FAO,1985)} \qquad \text{eq. 3}$$

where,

LR = leaching requirement

EC_w = As previously defined

EC_e = the average soil salinity as measured on a soil saturation extract and corresponding to 90% yield target (Appendix 7.2)

Table 7.4 shows the recommended leaching requirement for all crops given the target yield and ECw at each site. The actual crop production will, however, depend on the amount of leaching provided. Depending on the exact crop rotation adopted, the most sensitive crop should be used for leaching requirement assessment. Given the usual inefficiencies of water application, the water losses due to deep percolation, normally between 15% for drip irrigation and 50% for some of the surface irrigation methods, almost satisfy the leaching requirement for salinity control presented in table 7.4.

Table 7.4 Leaching fraction using As Samra effluent and Zarqa River water

Crop type	Leaching requirements					
	Site 4	Site 5	Site 5.1	Site 7	Site 100	Site 600
Sweet Corn	0.26	0.25	0.26	0.25	0.28	0.24
Barley	0.05	0.05	0.05	0.05	0.06	0.05
Alfalfa	0.18	0.17	0.18	0.17	0.19	0.17
Citrus	0.27	0.27	0.27	0.26	0.29	0.25
Apricots	0.34	0.34	0.34	0.33	0.37	0.32
Grape	0.26	0.25	0.26	0.25	0.28	0.24
Tomato	0.17	0.17	0.17	0.17	0.18	0.16
Cucumber	0.18	0.18	0.18	0.18	0.20	0.17
Pepper	0.30	0.30	0.30	0.29	0.33	0.28
Beans	0.51	0.51	0.52	0.50	0.56	0.47
Cabbage	0.22	0.22	0.22	0.22	0.24	0.21
Potatoes	0.26	0.25	0.26	0.25	0.28	0.24
Onion	0.39	0.39	0.40	0.38	0.43	0.37
Lettuce	0.32	0.32	0.32	0.31	0.35	0.30
Spinach	0.18	0.18	0.18	0.18	0.20	0.17
Radish	0.34	0.34	0.34	0.33	0.37	0.32
Carrots	0.43	0.42	0.43	0.42	0.47	0.40
Strawberry	-	-	-	-	-	0.59

Notes:

- *blank spaces indicates that crop is not presently cultivated in that area*
- *leaching requirements are based on targeted 90% crop yield and average EC_w during the irrigation period (4/98-10/98), depicted in table 7.1.*
- *leaching fraction is the minimum proportion of irrigation water supplied that must be drained through the root zone to control soil salinity at the given specific level (FAO, 1993)*
- *for site location refer to Map 7.1*

Hence, the actual extra water needed to accomplish leaching will ultimately depend on the irrigation method used as determined by water quality and health requirements, and the estimated contribution of effective rainfall in leaching, based on local conditions.

Factors that should be considered in such assessment include average monthly evapotranspiration, mean monthly rainfall, antecedent soil moisture condition and its water-holding capacity, infiltration rate of the soil and rainfall intensity. Based on annual precipitation amounts in the Seil Al Zarqa area and the Middle Jordan Valley of about 400mm and 180mm respectively, it is expected that a certain amount of natural leaching would have occurred in both areas by the onset of the irrigation period under study, which should not be neglected. Winter leaching can be enhanced even in a dry year by early winter irrigation to refill the soil profile with water before the rain. The latter will then complete the soil water replenishment and accomplish all or part of the required leaching with almost salt-free water.

It is important to realise that the potential yields given in table 7.3 do not provide accurate quantitative values representing those interactions which might influence crop response to salinity. Actual yield response depends on other factors such as specific concentration, climatic and soil conditions, water availability, crop variety and stage of growth. While such values are not exact, they are nevertheless used to predict the relative effect of salinity on the different crops, assuming other factors are not limiting. Potential yields will be further decreased by increased salinity in the surface soil during germination and early seedling stage. With a leaching fraction of 15%, and a 40-30-20-10-crop water use pattern, the soil salinity in the upper quarter of the rooting depth will be at its maximum when using site 100. This is, however, less than the maximum recommended by FAO at 4 to 5 dS/m. Hence, given the water quality at all sites, it is unlikely that crop production potential will be effected by slowed germination and reduced crop stand, unless high salt concentrations are indigenous to the soil and/or poor drainage conditions exist. While the latter poses no problem, due to adequate natural and artificial drainage in the area, the former could result in the complete failure of some crops, especially in the Middle Jordan Valley, where the occurrence of saline soils is quite common, thereby necessitating reclamation leaching to restore soil productivity.

Salinity control

Control of salts in the soil can be achieved by controlling water movement in the soil. This involves several interrelated factors such as (FAO, 1985 and Arar, 1988):

- quantities and distribution of rainfall;
- quantities and qualities of irrigation water;
- prevailing drainage conditions;

- methods of irrigation and leaching practices;
- land preparation for better water distribution;
- timing of irrigation to prevent excessive root zone depletion and water stress;
- types of crops; and
- soil type and topography.

Leaching practices

Provided that crop tolerance is not exceeded for extended or critical periods of time, leaching can be done at any time. Soil and crop monitoring should thereby be useful in determining the need for leaching. The following procedures are suggested for increasing the efficiency of leaching and reducing the amount of water needed:

- leaching during the early irrigation season since evapotranspiration losses are lower.
- use tillage to slow overland water flow.
- use sprinkler irrigation at an application rate below the soil infiltration rate, since unsaturated flow is known to be more efficient than saturated flow for leaching.
- use alternate ponding and drying instead of continuous ponding. The former is more efficient in leaching and less wasteful, though more time consuming.
- schedule leaching, where possible, at periods of low crop water use. Alternatively, after the cropping season.
- for low infiltration rates, pre-plant irrigation or off-season leaching should prevent excessive water application during the crop season.

Appendix 8.7 gives some details on leaching (as ponding) in the pilot sites.

Irrigation methods

The method of irrigation directly affects the way salts accumulate in the soil. With furrow irrigation using the moderately saline water for all sites, it is difficult to obtain a satisfactory stand of the crops, as salinity may concentrate five to ten times on top of ridges and hence affect germination. Placement of seed to avoid the area likely to be salinized is therefore required. In general, fewer problems are encountered with border irrigation (Arar, 1988). Basin irrigation with good land-levelling is essential for salinity leaching. Land-levelling is most appropriate for salinity leaching. Land-levelling is also essential to furrow, border and basin irrigation. Inadequate leaching may also be caused by differences in the rate and time available for infiltration.

Since the depth of water applied with surface irrigation methods cannot be easily adjusted per irrigation, more frequent irrigation for salinity control may result in an unacceptable increase in depth of water applied and a corresponding decrease in water use efficiency. Hence, it may be easier to increase the frequency of irrigation with sprinklers or drip rather than with surface irrigation. However, given the chloride and sodium ion concentrations in different sites, the high temperatures and low humidity during the irrigation period, leaf burn of sensitive crops is expected with sprinkler irrigation. These crops are listed in tables 7.5 and 7.6. Night sprinkling has proved effective in reducing or eliminating both sodium and chloride toxicity due to foliar injury. Other management options include avoiding periods of high wind, moving of laterals with the main wind direction, increasing sprinkler rotation speed and rate of application if the soil infiltration rate permits.

Table 7.5 Potential effect of Cl^- using As Samra effluent and Zarqa River water

Effect of Cl^-	Sampling sites		
	Site 4	Site 100	Site 600
A-surface irrigation			
• Degree of restriction on use	Severe	Severe	Severe
• Annual crops likely to suffer yield reduction due to Cl^- salinity	Beans and Carrots	Onion, Potato and Cabbage	As for site 100
• Fruit crops likely to develop leaf injury	Rough lemon, sour and sweet orange, stone fruits and grapes	As for site 4	As for site 4 +Strawberry
B- Sprinkler irrigation			
• Degree of restriction on use	SMR	SMR	SMR
• Annual and tree crops likely to develop foliar injury	Almond, Apricot, Citrus, Grape, Pepper, Potato, Tomato, Alfalfa, Barley, Corn (maize), and Cucumber	Almond, Apricot, Citrus, Pepper, Potato, and Tomato	Almond, Apricot, and Citrus

For site location refer to Map 7.1
SMR means severe to moderate restriction

Table 7.6 Potential effect of Na^+ using As Samra effluent and Zarqa River water

Effect of Na+	Sampling sites		
	Site 4	Site 100	Site 600
A-surface irrigation			
Degree of restriction on use	Severe	Severe	Severe
Crops likely to develop sodium toxicity	Beans and Carrots, Rough lemon, sour and sweet orange, Stone fruits and grapes	As for site 4 +Onion, Potato and Cabbage	As for site 100+Strawberry
B- Sprinkler irrigation			
Degree of restriction on use	SMR	SMR	SMR
Crops likely to develop foliar injury	Almond, Apricot, Citrus, Grape, Pepper, Potato, Tomato, Alfalfa, Barley, Corn (maize), and Cucumber	Almond, Apricot, Citrus, Pepper, Potato, and Tomato	Almond, Apricot, and Citrus

For site location refer to Map 7.1
SMR means severe to moderate restriction

Drip irrigation has provided better yields with higher salinity water (EC_w>1dS/m), due to daily replenishment of water used by crop, and low moisture tension levels maintained throughout the season. However, salt may accumulate at the outside edges of the area wetted by emitters and might be moved by rain into the root zone. It is therefore recommended that regular irrigations continue during a period of rain and that new plantings in salty areas should not be made without prior leaching. Careful management of drip irrigation systems is required to decrease clogging of emitters (see section 7.4). Filtration is needed to prevent immediate clogging by large particles and rapid granular filtration is recommended to remove particles, with irregular shapes. Chemical pre-treatments with oxidants and flocculants might also be needed.

7.1.2 Water Electrical Conductivity (EC_w) and Sodium Adsorption Ratio (SAR)

According to the FAO guidelines (Appendix 7.3), evaluating water using EC_w and SAR together at all sites does not present any degree of restriction on the infiltration rate of water into the soil (permeability). SAR defined as a relative proportion of sodium ions to calcium and magnesium ions:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{(\mathrm{Ca}+\mathrm{Mg})/2}} \text{ (FAO,1985)} \qquad \text{eq. 4}$$

Sodium effects soil structure through cation absorption, mainly on clay and fine silt fractions. As the percentage of sodium rises in relation to other cations, clay disperses, thus filling small pore spaces and hence results in greatly reduced infiltration, particularly at the soil surface, a decrease in water supply to crop between irrigations and reduced soil aeration capacity. Adjusted sodium adsorption ratio (adj R_{Na}) is a recent modification of Eq. 4 that takes into account changes in calcium solubility in soil water:

$$\text{adj}\, R_{Na} = \frac{Na}{\sqrt{(Ca_x + Mg)/2}} \text{ (FAO,1985)} \qquad \text{eq. 5}$$

The value of Ca_x is obtained from Appendix 7.4. The adj R_{Na} value is preferred in irrigation applications with treated sewagewater because it reflects the changes in calcium in the soil water more accurately. At a given sodium adsorption ratio, the infiltration increases as salinity increases, or decreases as salinity decreases.

Therefore, SAR or adjusted R_{Na} should be used in combination with EC_w of irrigation water to evaluate the potential permeability problem as shown in Appendix 7.3. However, RSS data during the irrigation period do not allow such estimation. A quick review of the annual average values of Na, Ca, Mg and HCO_3 concentrations in sites 100 and 600 indicates adj R_{Na} at 7.1 and 6.04, respectively. These values are higher than the average SAR values given in table 7.1 for both sites. However, given the EC_w of the water, no unfavourable changes to soil chemistry would be expected and hence infiltration problems are not foreseen, even when using clay soils.

7.1.3 Specific ion toxicity

Chloride ions. Assuming that soil salinity consists predominantly of Cl salts accumulated from irrigation water, then multiplying the maximum allowable soil salinity without yield reduction (soil salinity threshold) given in the salt tolerance tables of Appendix 7.2 by 10 gives the crop tolerance to Cl^- salinity in meq/l (Mass, 1984). The FAO toxicity guidelines of Appendix 7.3 indicates a severe restriction on the use of As Samra treated sewagewater for surface irrigation and slight to moderate restriction on use for sprinkler irrigation. Previous quantitative data on the maximum Cl^- concentrations permissible in the irrigation water (Appendix 7.5) indicate possible leaf injury of the tree crops shown in table 7.5 when applying surface irrigation. Hence, adequate leaching will be required. Estimates of the latter indicate that if salinity leaching is met, it will be more than sufficient to leach chloride ions.

Based on relative tolerance of selected crops to foliar injury (Appendix 7.6), table 7.5 also shows the crops expected to suffer from leaf burn when using sprinkler irrigation. The list is not all-inclusive, as many crop tolerances to chloride are not yet all documented.

Sodium ions. The SAR of the water indicates a slight to moderate restriction on use for surface irrigation of most tree crops and woody plants. Those relevant to the local climate and sensitive to the given water quality are listed in table 7.6. They are extracted from the relative sodium tolerance values presented in Appendix 7.7, and based on estimates of the soil Exchangeable Sodium Percentage (ESP) expected to result from long-term use of the given water SAR in each site (Appendix 7.8). Depending on the specific crop tolerance to Na$^+$, sodium injury can occur following surface irrigation for an extended period of time (many days or weeks) when accumulation of toxic levels of Na$^+$ is reached in the leaves.

Adequate leaching to maintain a low soil SAR is therefore required. It is expected, however, that water allocated for leaching of Cl$^-$ whenever needed should be sufficient to leach sodium ions. Crops likely to develop foliar injury when using overhead sprinkler irrigation are also listed in table 7.6.

Boron Toxicity. Table 7.7 indicates that the concentration of this element is within the acceptable limits for many crops that can be grown in the study area. However, at given Boron concentrations in As Samra effluent for all sites, some very sensitive and sensitive crops can be affected (Appendix 7.9). Boron toxicity is hence inevitable when growing lemon using such effluent. Since documented tolerance of various crops to Boron is based on a maximum permissible concentration range in the soil water, it becomes quite difficult to identify the specific concentration at which Boron toxicity would occur, if at all, given the water quality of each site. Depending on crop tolerance, it can be generally stated that the Boron concentrations pose toxicity potential to sensitive crops in all sites (table 7.7). Use of more tolerant crops is therefore recommended if adequate leaching cannot be provided.

Table 7.7 Potential effect of Boron toxicity using As Samra effluent and Zarqa River water

Effect of B	Sampling sites			
	Site 4	Site 7	Site 100	Site 600
• Degree of restriction on use	None	None	None	None
• Expected crop toxicity	Lemon		Lemon	Lemon
• Potential crop toxicity due to Boron sensitivity	Grapefruit, orange, Apricot, Peach	As for site 4	As for site 4+ Onion	As for site 100

For site location refer to Map 7.1

Heavy elements. The concentrations of all the heavy elements measured by RSS (Table 7.12) indicate no restriction on use at all sites. However, continuous monitoring of these parameters is required as more industries get connected to the sewer system. Presently, out of 108 wet-type industrial operations, 50 are connected to the Amman-Zarqa sanitary sewer and 53 discharge to surface water (RSS, 1999). Although many industries have on-site treatment facilities, they seem to be inadequate and hence might affect As Samra performance. Despite government industrial limitations, approximately one half the industries are violating waste discharge requirements (RSS, 1999) and heavy elements such as Fe, Pb, Mn, Zn, Cu, Cr and Cd have been reportedly increasing in the Amman-Zarqa basin. Monitoring of industrial compliance is therefore necessary.

7.1.4 Total Nitrogen and Total Phosphorus (T-N and T-P)

The total nitrogen concentration of the water at site 4 and 100 (table 7.1) presents a severe restriction on its use for irrigation, whereas that at site 600 indicates a slight to moderate restriction on use. The quantity of nitrogen contained in As Samra effluent is excessive even by the standards of tolerant crops. Considering the T-N concentration at 81 mg/l at site 4 (1 mg/l = 1kg/1000 m^3) and assuming a cropping pattern similar to that prevailing in the climatic area in which the plant is located, a weighted average effluent application of 479 mm/Yr (RSS, 1999) would provide an average of 388 kg nitrogen per hectare. This, however, far exceeds the amount reported to have adverse effects on such crops as oranges and potatoes (Taha, 1993). Excess nitrogen application will affect yield and product quality of tomatoes for processing, potatoes, citrus, peaches, apricots, apples and grapes (Bouwer and Idelovitch, 1987). Table 7.8 shows the average amounts of nitrogen applied by irrigation given the T-N concentrations at different sites. These values, however, may well be exceeded depending on the crop water application rate. Research in Israel indicates that N concentrations of about 15-20 mg/l are required in the effluent in order not to exceed the requirements of most crops. The amounts of nitrogen required by different crops vary. Typical nitrogen requirements for some crops are presented in table 7.9. Some of the nitrogen not used by crops will leach out of the soil, mostly as nitrate, hence posing undesirable nitrate pollution of the ground water.

Table 7.8 Average amounts of Nitrogen and Phosphorus provided by As Samra effluent and selected sites along the Zarqa River (Kg / ha)

Sites	Nitrogen [c]	Phosphorus [d]
Site 4 [a]	388	93
Site 100 [a]	295	62
Site 600 [b]	151	36

[a] Weighted average application rate representing the cropping pattern in the Zarqa River area= 479 mm / Yr

[b] Weighted average application rate representing the cropping pattern in the Middle Jordan Valley= 535mm / Yr

[c] Based on T-N concentration during the irrigation period (table 7.1)

[d] Based on T-P concentration during the irrigation period (table 7.1)

for site location refer to Map 7.1

Table 7.9 Nutrient uptake rates for various crops

Crop	Uptake (kg / ha)	
	Nitrogen	Phosphorus
Alfalfa	224-538	22-34
Barley	71	17
Corn	174-193	19-28
Potatoes	230	22
Wheat	56-91	17

Source: Bouwer and Idelovitch (1987)

Based on the average T-P concentrations during the study period (table 7.1), the amount of phosphorus applied by the water of the different sites is estimated in table 7.8. Again As Samra effluent has phosphorus in excess of that required by all the crops listed in table 7.9. Despite the limited information on the effect of irrigation with phosphorus rich effluents, many soils are successfully irrigated with treated sewagewater having concentrations of about 5-10 mg/l (mostly as PO_4).

The fertiliser value of the As Samra effluent (site 4) and KTD water (site 600) have been estimated by Al-Salem (1992) at US$ 213 and US$ 42 per 1000 m^3 respectively. This adds up to about US$ 8.9 million considering 1991 flows, almost the value of fertilisers Jordan imported in 1986 (Al Salem, 1992). This suggests that the fertilising action of the water at all sites should not be ignored. Depending on crop nutrient requirements and their availability in the soil, evaluation of different nutrient contents with respect to crop suitability can be made on an individual crop basis for each site, and thus subsequent decisions on the need for dilution and supplemental fertilisers can be made.

A tailoring in the supply of nutrients is required for nutrient control. This arises from the sigmoid pattern of plant growth. During the active growth period an abundant supply of nutrients should be provided, while the lowest amount is required during the initial growth and ripening stages. Blending or changing water supplies (if possible) should be helpful. Such an alternative during the ripening period will also minimise the pathogen contamination of crops. During the period of low nutrient requirements, light irrigation would be advisable, whereby the minimum depth required meeting the crop water demand shall be applied. If water applied nutrients are still excessive, irrigation to cause a moderate but increasing water stress, as the crop approaches maturity, is required. During the non-irrigation season, crop rotations should be planned to utilise the residual nutrients in the soil.

Other options for nutrient control include control of the sources of nutrients in the Zarqa River catchment area including the overuse of fertilisers and restricting the use of phosphorus in industrial detergents. Treatment procedures to remove nutrients from the sewage include denitrification, phosphate precipitation, and ammonia volatisation. These processes, however, might be prohibitively expensive for irrigation. Other options include soil aquifer treatment via ground water recharge (Bouwer and Idelovitch, 1987), if applicable. The latter is achieved using rapid infiltration basins to put primary or secondary treated sewagewater underground, and wells or drains to collect the treated sewagewater after it has been renovated.

7.1.5 Total Suspended Solid (TSS), Total Dissolved Solid (TDS), and pH

The concentration of these elements in the water at all sites presents high potential for the clogging of emitters in drip irrigation systems (Appendix 7.10). Table 7.10 expresses this potential in terms of degree of restriction on use. Plugging of emitters can be decreased if the system is properly planned and designed. A complete water analysis should therefore be conducted before a system is designed. Water quality tests needed include major inorganic salts, hardness, suspended solid, TDS, BOD, COD, organic matter, micro-organisms and others (FAO, 1985).

The main cause of clogging is solid particles in suspended states. Filtration can prevent immediate blockage by removing particles larger than the width of the emitter flow path. Granular filtration helps to remove particles with irregular shapes.

Table 7.10 Influence of water quality on the potential for drip clogging problems using As Samra effluent and Zarqa River water.

Parameter	Degree of restriction on use					
	Site 4	Site 5	Site 5.1	Site 7	Site100	Site600
TDS	SMR	SMR	SMR	SMR	SMR	SMR
pH	SMR	SMR	SMR	SMR	Severe	SMR
TSS	Severe	Severe	Severe	None	SMR	None

SMR means slight to moderate restriction on use.
For site location refer to Map 7.1.

Other methods include efficient backwashing of the filters and flushing the ends of the line, and installing long laterals when the topography permits (Bouwer and Idelovitch, 1987). Algae and other growth enhanced by the high nutrient levels in all sites would also contribute to the clogging problems. The use of oxidants such as chlorine or chloride dioxide is an effective control measure, though costly, and requires careful management for safe use. Precipitation of calcium carbonate enhanced by high temperatures or high pH is another cause of plugging. Control of pH, or cleaning the system periodically should prevent deposits building up to such a level where clogging might occur.

7.1.6 Microbiological quality

In comparing the Jordanian guidelines (Appendix 7.11) concerning treated sewagewater use in irrigation with the microbiological quality guidelines of the World Health Organisation (WHO) (Appendix 7.12), we found that the local guidelines are more strict in the use of treated sewagewater in the irrigation of crops that are eaten uncooked. In accordance with this consideration we will use the Jordanian guidelines for sites 4 and 5 and WHO guidelines for sites 5.1, 7, 100 and 600, since in latter sites the treated sewagewater is mixed with other sources of fresh water.

Referring to table 7.1 the water quality for sites 4, 5, 5.1, 7 and 100 are not suitable for use in the irrigation of crops that are eaten uncooked, like tomatoes, cucumber, lettuce, carrots, radish, and cabbage. But it can be used to irrigate fodder crops and fruit trees conditional upon irrigation being stopped two weeks prior to fruit harvesting, and the discarding the fruit that has fallen to the ground through harvesting practices. Besides that, sprinkler irrigation must not been used in irrigating fruit trees. Animals can go to the field for feed after two weeks from the last irrigation. For site 600 there is no restriction on use, which includes irrigation of all crops that are eaten cooked or uncooked, fruit trees, landscape and parks.

For all sites we found that the As Samra treatment plant is effective in removing nematode eggs, since intestinal nematode eggs are completely removed and are not present downstream. Continuous monitoring is required to determine whether the effluent is in compliance with the guidelines during the irrigation season.

Crop restrictions along the Zarqa River are necessary and government regulations in this regard are justified. Measures to reduce the faecal coliform contamination include waste containment facilities to prevent livestock manure and waste from running off directly into the river water. Table 7.11 shows the conditions of use in respect of the different sites' water and the added measures required for health protection, with respect to application methods and control of human exposure.

Table 7.11 Conditions of irrigation use of As Samra effluent and Zarqa River water

Sampling site	Conditions of use	Application method	Control of human exposure
Site 4, 5, 5.1, 7, 100	Category B Crops • Cereal crops, industrial crops, fodder crops and pasture	• Sprinkler irrigation is allowed if there is a buffer zone of 50-100m from houses and roads	• Health education. • Provision of adequate potable water supplies. • Irrigation channels, pipes and outlets should be clearly marked. • Outlet fittings designed to prevent misuse. • Adequate medical facilities. • Immunisation of highly exposed group if feasible, e.g. immunisation against typhoid and protection against hepatitis A
	• Fruit trees	• Sprinkler irrigation should not be used. Irrigation should stop 2 weeks before harvest and no fruit should be picked off the ground.	
Site 600	Category A Crops [a] • Irrigation of all crops including those to be eaten uncooked, sports fields and public parks	• Any irrigation method. The most dominant method in this area is drip irrigation	• Health education. • Provision of adequate potable water supplies.

[a] Provided that reliable disinfecting efficiency is ensured. Alternatively, the As Samra treatment plant should be upgraded to control faecal coliforms. Regular monitoring of the effluent during the irrigation period is required.

For site location refer to Map 7.1

Drip or subsurface irrigation can be used in sites 5, 5.1, 7, and 100 (see Map 7.1). Besides using water more efficiently and producing higher yields, it prevents any contamination from reaching the crop or the workers and hence protects the health of both consumers and workers. However, clogging of emitters is a serious problem (section 7.1.5), therefore requiring filtration.

Decisions on crop restrictions are influenced by the demand for the crops allowed, profitability, market pressures in favour of excluded crops, and the crop production potential (Taha, 1993). Crop selection and controlled application methods as a means of health protection require a strong institutional framework. Present experience with crop restriction in Jordan indicates it is being successfully enforced. A possible problem for the future is the expansion of the irrigated areas as more effluent is discharged along the Zarqa River. Increased capacity to monitor and control compliance with regulations should therefore be afforded. Farmers must be advised on the need for crop restrictions.

Other health protection measures are shown in table 7.11. It should be noted that the potential health risk involved in the use of site 5, 5.1, 7, 100 water are further reduced by technical factors involving the detention of water in storage ponds. Experience with farmers in Jordan indicates the use of storage ponds before water is distributed through sprinkler or drip irrigation. In addition, the normal use of sand filters in drip irrigation provides additional tertiary treatment at no expense and can therefore be used with more confidence.

Aerosols can result in transport of viruses and bacteria when sprinkler irrigation with the inferior water quality in the above-mentioned sites is used. However, studies conducted in areas with similar climatic conditions could not find any conclusive epidemiological evidence of adverse health effects on the farm workers (Shuval and Fattal, 1980). Viruses and bacteria in aerosols are inactivated by warm temperature, low humidity and sunlight; typical climatic features of the study area during the 'irrigation period' will further reduce the risk if it exists. For further protection, arrangements can be made to operate the sprinklers after the agricultural workers have left the fields. The natural die-off of pathogens in the field constitutes additional safety when the water is applied to the crops and soil, and provides a further reduction of pathogens within a few days after application.

7.2 Water quality

The following sample sites were selected for water quality assessment. These include sites 3, 4, 5, 5.1, 7, 100, and 600 (Map 7.1). Sites 3 and 4 represent the inlet and outlet of the As Samra treatment plant respectively, and are selected to evaluate the plant's removal efficiency with regard to certain parameters. Sites 5, 5.1 and 7 represent the flow of As Samra effluent along the Zarqa River (Zone A and Zone B), site 100 represent the inlet of KTD, and 600 represent water discharged from the KTD to the Jordan Valley (Zone C). It is realised that KTD water quality downstream from the outlet becomes more saline before it is ultimately distributed to the farmers in the Middle Jordan Valley. However, it is assumed that action to reduce the salinity load of KTD water downstream of site 600 will be taken through the construction of a pipeline currently proposed to transport water from the KTD to the Jordan Valley. This implies that the water quality at site 600 should represent that at the farm inlet presently using KTD water in the Zarqa Triangle Project.

Table 7.12 gives the water quality data measured at the previously mentioned sampling sites based on the latest reports provided by RSS (1999, 2000) for the year preceding the start of analysis. When table 7.12 is compared with table 7.1, some variability in certain parameters is visible. For some (TDS, NH_4-N, NO_3-N), levels are fairly stable, for others (SAR, TFCC) there are significant variations that need to be adjusted. The biggest differences were in faecal coliform. These contradictions exist because certain parameters were missing and these parameters were obtained using the latest available information from other sources. Despite the inconsistency involved in a few cases, it is believed that the available data should provide, in broad terms, a good indication of the water quality in each site and zone and has therefore been used to determine factors effecting As Samra effluent quality both at the discharge point and as it travels to its final destination in the KTD. Effluents from the ponds (site 4) are high in Total Suspended Solids (TSS): 150 mg/l with a Biological Oxygen Demand (BOD-5) of 124 mg/l. Higher TSS concentrations are observed during summer due to the increased concentration of algae in the effluent.

Table 7.12 Average quality of As Samra effluent and selected sites along Zarqa River

	Parameter	Unit	Sampling sites						
			3[a]	4[a]	5[a]	5.1[a]	7[a]	100[b]	600[b]
General Parameters	TSS	mg/l	456	109	107	112	66	118	14
	BOD-5	mg/l	579	118	95	66	49	47	6
	BOD-5 (f)	mg/l	204	50	22	13	10	-	-
	COD	mg/l	1119	310	274	209	156	183	45
	SO4	mg/l	103	26	28	80	105	129	175
	NH4-N	mg/l	76	72	67	54	40	43	21
	NO3-N	mg/l	-	16.2	11.5	11.9	-	8.34	2.9
	T-N	mg/l	109	89	-	-	-	65.12	28.37
	T-P	mg/l	15.8	19.4	-	-	-	13.0	6.8
	MBAS	mg/l	29.5	17.5	-	-	-	1.87	0.46
	B	mg/l	0.48	0.66	0.68	0.66	0.64	0.66	0.60
	TDS	mg/l	1186	1232	1230	1316	1345	1426	1379
	EC	µS/cm	2334	2539	2522	2561	2503	2703	2483
	DO	mg/l	-	5.2	5.9	7.3	6.4	6.45	3.8
	pH		7.17	7.87	8.01	7.97	8.00	8.12	7.84
	Na	mg/l	225	252	-	-	-	276	254
	SAR		-	5.76	-	-	-	5.25	4.67
Heavy metals	Al	mg/l	0.8	0.2	-	-	-	0.3	<0.1
	As	mg/l	<0.005	<0.005	-	-	-	<0.005	<0.005
	Cd	mg/l	<0.004	<0.004	-	-	-	<0.003	<0.003
	Cr	mg/l	0.04	0.03	-	-	-	<0.025	<0.025
	Cu	mg/l	0.03	0.02	-	-	-	<0.025	<0.025
	Fe	mg/l	1.57	0.17	-	-	-	0.17	0.2
	Li	mg/l	0.03	0.03	-	-	-	<0.025	0.038
	Mn	mg/l	0.09	0.07	-	-	-	0.06	0.22
	Ni	mg/l	<0.1	<0.1	-	-	-	<0.02	<0.02
	Pb	mg/l	0.01	<0.01	-	-	-	<0.01	<0.01
	Zn	mg/l	0.44	0.04	-	-	-	0.03	<0.01-0.03
	Hg	mg/l	<0.001	<0.001	-	-	-	<0.001	<0.001
Micro-biological	TFCC	MPN/100ml	-	2.8E+04	1.8E+04	9.2E+03	1.3E+04	3.4E+03	3.8E+02
	Nematodes	Eggs/l	-	0	-	-	-	0	0

[a] *Source: RSS (1999). The average is the arithmetic mean of measurements taken between March 1998 - March 1999.*

[b] *Source: RSS (2000). The average is the arithmetic mean of measurements taken between April 1999 - February 2000.*

For site locations refer to Map 7.1.

As the water travels along the stream course, successive reductions in the TSS occur due to the natural death of algae and the dilution effect of the springs and rain-water, especially at, and downstream of, site 5.1. The effluent organic pollution load, measured as BOD, ranges between 75 and 234 mg/l. Based on adopted Jordanian standards for treated sewagewater quality, As Samra ponds should achieve a mean BOD-5 filtered level of ≤ 29 mg/l (Bannayan, 1987), as compared with an average of 59 mg/l during the study period.

The high influent BOD-5 concentrations of 819 mg/l and 1254 mg/l representing Amman and Zarqa respectively, indicate very strong sewagewater discharged into the ponds. Underlying the effluent BOD-5 quality is a low per capita per day domestic water consumption estimated at 99 litres and increased hydraulic loads discharged into the system, with a subsequent reduction in the ponds' BOD removal efficiency.

The increase in SO_4 concentration in sites 5.1 and 7 has been attributed to the increase of SO_4 concentration in site 6 because of the industrial activity along the river and the increase of SO_4 concentration in the springs alongside the river. It is, however, expected that with the anaerobic decomposition of sulphate, containing organic compounds and the subsequent release of H_2S, clogging problems in localised irrigation may occur.

The ammonium nitrogen (NH_4-N) concentration in As Samra effluent of 76 mg/l as compared with an effluent concentration of 72 mg/l indicates the lack of oxygen necessary for nitrification. This is also confirmed by the low nitrate nitrogen (NO_3-N) concentrations in the effluent. As oxygenation of the former and dilution along the stream and in the KTD occur, a subsequent decrease in NH_4-N takes place with a simultaneous increase in NO_3-N concentrations. The high input of total nitrogen (T-N) and total phosphorus (T-P) from As Samra ponds supplies nutrients to the KTD. Other sources include phosphate-mining activities in the catchment area, and wastes reaching the Zarqa River. RSS analysis of KTD water during the study period indicates that the KTD is hypereutrophic. As a result various species of algae are present in its water. High concentrations of algae are also found in As Samra effluent and along the Zarqa River.

The algae population of the former is dominated by *Euglena* and *Chlamydomonas* species; the natural resident population of highly polluted ponds. Presently, the As Samra plant is removing 59% of Methylene Blue Active Substances (MBAS) in its ponds. Despite the general decrease in effluent MBAS concentrations it remains fairly high on aesthetic grounds, since very small concentrations are sufficient to cause foaming at all sites.

Until 1991 increasing concentrations of boron were observed. Government regulations restricting the use of boron in detergents however, has rectified this situation. Hence the decrease in boron concentrations at all sites since then.

Evaporation from the ponds increases the TDS concentration at the discharge point of As Samra relative to that at the inlet. In average over the study period, RSS records show TDS concentrations representing Amman and Zarqa sewagewater, at 1127 and 1672 mg/l respectively. Chemical analysis of different water samples in these cities show corresponding average TDS values of 465 and 1027 mg/l. Assuming TDS increments due to one cycle of use similar to that found in Israel at 370 mg/l, an average 284 mg/l of TDS would therefore be attributed, during the same period, to industrial sources and low per capita domestic water consumption (Taha, 1993). Higher TDS contributions are, however, expected during the dry periods when water rationing is practised countrywide.

Increase in TDS and EC_w values are observed in sites 4 and 5 respectively. This is due to the evaporation of water from the ponds and along wadi Dhuleil. As the effluent gets diluted, a subsequent decrease in these values occurs. The water downstream of As Samra becomes more oxygen rich due to increased aeration. The pH values of the water at all sites indicate a tendency towards alkalinity. As for the heavy metal concentrations, table 7.12 indicates that they are below the detection limits in both As Samra effluent (Site 4) and the KTD (site 100).

The number of faecal coliforms (Table 7.12), which is above the Jordanian standard ($1.00x10^{+03}$), indicates that As Samra ponds are not performing as well as a conventionally designed and constructed stabilisation pond system. A review of Water Authority of Jordan (WAJ) monthly operation records for 1998 indicates a maximum hydraulic load of 168,857 m^3/day discharges into the ponds. Based on WAJ estimates of the sludge depth in each anaerobic train, the effective volume of the ponds is found to be 2.46 million m^3. Hence, the actual retention time achieved in the ponds is approximately 17 days as compared with the designed 40 days. Saqqar (1987) identified other factors effecting faecal coliform removal in As Samra ponds. The latter found that the die-off rate of faecal coliform was an inverse function of BOD-5 loading, its concentration in the pond and pond depth and direct function of pond water temperature, pH and retention time. According to WHO guidelines, a total retention time of at least 16-20 days are required in a hot climate to reduce bacterial numbers to the guideline value of 1000 MPN/100ml. Clearly, there is a need to achieve the same value under the local conditions of the plant during summer and winter periods.

Effluent chlorination was applied in the past to maintain a faecal coliform level of < 1000 MPN/100 ml in the discharge to Wadi Dhuleil (site 4). This is believed to be costly and unreliable due to the irregular availability of chlorine gas. Considering the 10-15 mg/l at which the latter is dosed into the final effluent, 1-2 tons of chlorine are on average released daily into sewage rich in organic material, and hence represent a possible contamination of the effluent with 'suspected carcinogenic' trihalomethanes (THMS). Re-growth of faecal coliform occurs in the chlorinated effluent downstream of the As Samra discharge point in Wadi Dhuleil (site 5), due to the high BOD and NH4-N concentrations and thus hinders further disinfections. Other factors contributing to the growth include waste disposal and run-off, agricultural operations and livestock feeding in the area.

RSS analysis for the intestinal nematodes; Ascaris, Trichuris, and Hookworms indicate their absence in sites 5.1, 100 and 600 due to their complete removal in passage through the As Samra system, as confirmed by WAJ operation records. This is due to the sufficiently long retention time in the pond for at least 17 days during the peak winter flow.

Finally, retaining the incoming water in the KTD has the general effect of improving its quality with regard to all the parameters discussed. This is attributable to:

- additional mixing of the inflows with rain water and the surface water reaching the dam;
- consumption of nutrients by the algae in the KTD;
- natural bacterial and algal die-off;
- decomposition of organic compounds; and
- precipitation of suspended solids during the retention period in the dam.

7.3 Treated sewagewater as a resource

Boom (2000) did research with the objective of identifying to what extent treated sewagewater can be seen as a crop nutrient source for crops grown in the Siel Al-Zarqa and the Middle Jordan Valley, and how this knowledge should be incorporated in prototyping farming systems. For a typical case of the Siel Al-Zarqa and the Middle Jordan Valley, where three zones were identified (Zone A, B, and C), the draw up of nutrient mass balances was used as a method to provide information concerning to what extent a proper management of treated sewagewater use would lead to higher production, a decline in fertiliser expenses and prevention of excessive nutrient build-up in the root zone.

She stated that insufficient treatment of raw sewage at the treatment plant (Khirbet Al-Samra) results in treated sewagewater in zone A, the closest to the treatment plant, containing levels of macro-nutrients outside the normal ranges of typical secondary treated sewagewater. Levels around 85 mg/l of N, 45 mg/l of P, and 40 mg/l of K were found as mean values. In general she found that in zone A and B, which, are located in Siel Al-Zarqa, the nutrient outflow is more than sufficiently covered by treated sewagewater applied, ranging from 2 to 7 times higher than the amounts needed for N and K and even up to 35 times higher for P. Within this calculation fertiliser is not needed in these zones to grow selected crops. The application of these excessive amounts through the treated sewagewater should seriously be taken into account as a source of groundwater contaminants. In zone C, which is located in the Middle Jordan Valley, the treated sewagewater, after mixing with other water resources at the King Talal Dam, applied to the fields is covering the nutrient outflows to a lesser extent. However, N, P, and K applications are excessive for two third of the crops and only for one third of the crops insufficient. The presence of these levels of macro-nutrient in treated sewagewater should be taken into consideration by reducing the amount of fertiliser used at the farms. Ignoring this fact leads to high expenses for farmers, nutrient accumulation in soils, a possible stimulation of vegetative growth and the hazards of environmental pollution through ground water contaminants.

She also concluded that the presence of a storage unit (KTD) along the tract of discharge of treated sewagewater could contribute to the stability of treated sewagewater. The nature and extent of all natural post-treatment processes should be studied, as this can give vital information as to the required level of treatment and the way in which this should be applied, in order to contribute to the creation of a sustainable agricultural system using treated sewagewater. Together with agronomists and irrigation engineers, solutions should be found for better methods of operation, in which the treated sewagewater does not lose its value of being a nutrient source for crops.

7.4 Salinisation

Kaspersma (2001) did research with the aim of identifying the salinity problems related to the use of treated sewagewater in irrigated agriculture in the Middle Jordan Valley. This subject is important for the design of a theoretical prototype as it focuses on the development of a sustainable agricultural system in Jordan. The research was conducted to assess the feasibility of using a water flow and solute transport model (SWAP model) to predict the leaching and salt accumulation in the soil under drip irrigation with treated sewagewater. Three sites were selected for field observation: site 1 was never used for drip irrigation and provides initial conditions for simulation of the model, site 2 was used for drip irrigation for four years and site 3 was used for drip irrigation for ten years.

It is a well-known fact that salts accumulate close to the soil surface as a result of evapotranspiration from the irrigated water. Salts can migrate downwards and reach the root zone, inhibiting water and nutrient uptake, and consequently effecting crop growth and yield. A certain amount of excess irrigation water is therefore required to percolate through the root zone in order to remove the accumulation of salt (Pescod, 1992). This process is called leaching.

In general she concluded that the salinity problem is not as severe as was expected at the beginning of the research at the three sites. Most likely, sufficient irrigation takes place to flush the salts to a layer lower than the root zone. This is shown in the majority of cases where the amount of percolated salts is more than the amount of salts added by irrigation water. She also noted that salinity at site 3 was lower than at sites 1 and 2. Having asked the farmers their opinions, she forwarded the possible explanation that cucumbers had been cultivated at site 3 for the previous two years, while in the case of site 2 this had been tomatoes. Tomatoes require more fertilisers than cucumbers and fertilisers cause higher salinity values, since they contain salts. Furthermore, leaching took place already in May for site 3 and at that time the quality of the leaching water was better than the water used in July to leach sites 2 and 1. This had been the case in earlier years too. Site 3 received a mix of water from KTD usually around 2.4 dS/m, and water from KAC with an EC_w value of 1.0-1.5 dS/m.

Result from the model simulation show that if salt concentrations continue to develop according to this trend, the water resources of Jordan will soon be incapable of supplying reasonable quality water in sufficient quantities. If possible, all sites should be leached with water that contains less salt from the KAC and possibilities to diminish the salt concentration in the water of the KTD should be studied.

7.5 Conclusion

Treated sewagewater use by means of agricultural irrigation offers a number of potential benefits. For example, land treatment or broad irrigation with treated sewagewater can reduce local pollution in receiving waters. This could be a considerable benefit for Jordan, where irrigation seasons are long and potentially receiving bodies of water have a limited adsorption capacity.

The second potential benefit, particularly attractive to Jordan, is that the use of treated sewagewater makes it possible to conserve limited water resources for economically beneficial irrigation projects in agriculture. Moreover, it enables farmers to expand irrigated areas and grow more food for human consumption, animal fodder, or industrial crops.

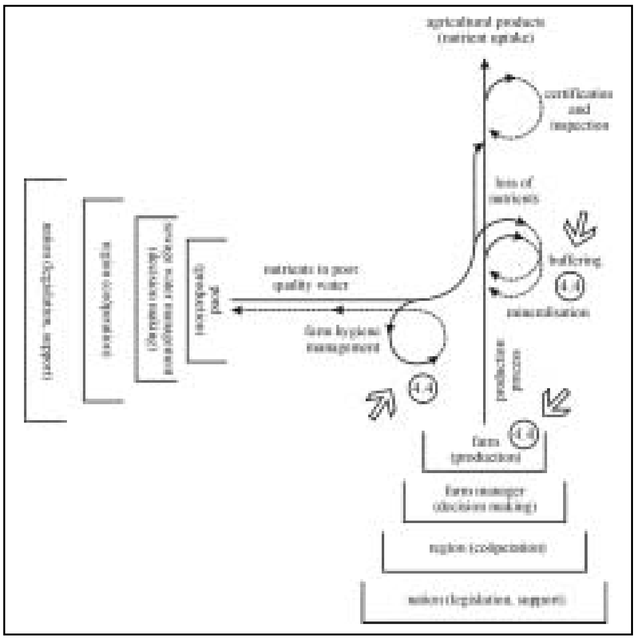
An additional benefit is that treated sewagewater use in irrigated agriculture will supply essentially all of the nitrogen, and most of the phosphorous and potassium, required by many crops, as well as important micronutrients. These nutrients are important for the agricultural economy of Jordan, where fertiliser costs for farmers are high. Organic matter in the treated sewagewater can also contribute to soil fertility and overall long-term fertility.

One concern here, however, is that the toxic chemicals, including heavy metals, in industrial and some municipal sewage might accumulate in food crops. For example, boron concentrations of 1mg/l or more are detrimental to citrus, although much higher concentrations can be applied to alfalfa, grapes, or tomatoes. In addition, high concentrations of sodium can change soil structure and thereby reduce fertility.

Where treated sewagewater is known to contain pathogens, its use for the irrigation of market vegetables can be proscribed. Vegetables or fruits that are exposed to raw sewagewater until they are harvested, and then eaten raw, carry the greatest risk of infection.

More than any other method of irrigation, flood irrigation wastes the most water, contaminates vegetable crops, and exposes farmers to more treated sewagewater. Drip irrigation is the most effective in minimising contact between the treated sewagewater, the crop, and the farmers. The drip method also uses less water and is beneficial to plant growth.

Chapter 8 – Designing of prototypes for using treated sewagewater on farms



Making pilot farms suitable for the regular use of treated sewagewater implied two things:

- create production soils that buffer nutrient residues left over from inefficient nutrient up take by crops; and
- create possibilities for preventing treated sewagewater from entering production land when the farmer wishes to do so for crop protection purpose.

Both objectives require the complete redesign of the present farm situation. Redesigning was done according to the so-called ‘prototyping method’ (Vereijken, 1994, 1995, 1996 and 1998). This method had been successful in numerous cases throughout Europe.

Prototyping involves six steps that farmers, facilitated by researchers, must take with regard to the structure and management of their own farms. The steps are:

- identify the problems and gather relevant local information (step 1);
- identify farmers’ objectives and translate them into quantifiable parameters (step 2);
- identify relevant farming methods and techniques (step 3);
- create a theoretical design for the farms involved (prototypes) (step 4);
- test the prototypes in practice (step 5);
- create managerial evaluation methods for yearly adaptation of the farm until the desired prototype has been realised (step 6).
- Repeat the whole process when the end result is not fully in line with the objectives, set in step 2 (step 7).

These steps are also in agreement with the steps proposed to farmers (see figure 6.1)

8.1 Identification of problems and gathering relevant local information

Information was obtained on three levels: from regional stakeholders, relevant publications and personal observations.

8.1.1 Regional stakeholders

Interviews were carried out among 124 people from different social groups: farmers, professionals, government employees, international organisations, policy-makers and other stakeholders, all involved in the use of treated sewagewater in irrigated agriculture in Seil Al-Zarqa and the Middle Jordan Valley. Applying open interviewing techniques (Fontana and Frey, 1994, and Chambers, 1985) gave us insight into what really concerned participants in terms of issues related to treated sewagewater use. Our aim was to collect qualitative verbal reports pertaining to these core issues, rather than hard facts and figures relating to certain opinions (Mettrick, 1993).

Our key informants were selected from the participants after the completion of random interviews in different zones. The selection was made on the basis of farmers' activities, level of interest and willingness to co-operate in solving the problems of treated sewagewater use. I wanted to know from them what they had done so far on irrigation with treated sewagewater. Their experiences in this particular respect and also more generally were of interest to me. We finally selected 26 informants. Six of them were farmers: one in zone A, two in zone B and three in zone C. Twenty of them were non-farming stakeholders: three from Jordan University, three from the Ministry of Agriculture, four from the Ministry of Water and Irrigation, two from the Jordan Valley Authority, three from the Water Authority, one from the World Health Organisation (WHO) and four from non-governmental organisations (NGO's). Interviews focused on the informants' visions and experiences concerning the use of treated sewagewater. Each interview was conducted without any interference from our side. We avoided exerting any influence on the thinking of interviewees, being only interested in the informant's own ideas and observations. Informants were reminded that we sought to learn from them, and that their knowledge was essential in achieving a sustainable use of treated sewagewater. All of the interviewees were satisfied with our approach. Indeed, great understanding was shown in respect of the procedure followed.

In determining the interviewing procedure I followed Mettrick (1993), who found that when interviewees are confronted with a detailed list of questions at the beginning of development-oriented research projects, it usually results in rather unsatisfactory outcomes. To avoid this, a checklist with reminders of topics to be discussed with stakeholders was used instead. This facilitated an informal but reliable interview, allowing sufficient room for the exploration of complicated or interesting topics. Any information of added value to the research was connected to the corresponding word in the checklist. In this manner, the interview ran more smoothly, and the recording and analysis of the information thus gathered was made easier.

8.1.2 Written sources

There are many publications on the use of treated sewagewater in agricultural production from various national and international organisations in Jordan (University of Jordan / Water and Environment Research and Study Centre publication No.22, 1998). Interest in treated sewagewater use in Jordan has been recorded since 1985, when the As Samra treatment plant was constructed and the effluent was discharged into the Zarqa River and the KTD.

Analysis of this literature demonstrates how researchers tackled issues related to treated sewagewater use in irrigated agriculture. However, results indicate that researchers, using conventional design and analytical procedures, had little confidence in the knowledge of farmers or other stakeholders (Da Silva, 1999). Conversely, Hamilton (1995) and Mettrick (1993) accept that the lack of confidence shown with regard to experimental results from research centres arises from results having too much to do with tackling the problems concerning the use of treated sewagewater rather than actually removing the cause of the problems i. e. what factors underlie a farmer’s refusal to use treated sewagewater?

8.1.3 Personal observations

According to Mettrick (1993) and Engel (1997) information gathered from interviews and bibliographical studies must be validated by direct field observations. Most bibliographical information refers to situations that differ from the one under focus in our project. Validation was carried out by direct field checks and observations and this was cross-checked in discussions with key informants. Direct field observation also served another goal. It helped to reveal problems or issues not immediately apparent to the stakeholders concerned.

Twenty-four field trips were made during this phase. Four days in zone A, eight days in zone B and twelve days in zone C. During each trip we observed all that we thought might be relevant in understanding the situation of treated sewagewater use as a whole. This included: changes in the quality of water from its discharge point at the treatment plant to reaching the farmers, the kind of crops grown in each zone, and problems associated with the use of treated sewagewater in crop production. Furthermore, during visits to farmers we talked with their rural labourers, as most of them actually live on the farm. They clearly had wide practical experience, not only related to farming aspects but also concerning the behaviour of natural resources relevant to farmers (biodiversity, climate, droughts, etc.).

Nevertheless, these visits revealed that farmers have little idea about how to deal with treated sewagewater as production factor. Farmers in zones A and B know that treated sewagewater has a nutritional value. Streams flowing close to the fields made it tempting for them to add as much water as they wanted without restriction or paying for it (excessive irrigation is practised). Farmers in zone C receive their water permanently from the Jordan Valley Authority. They have to pay for it, however. Consequently, we found them using irrigation water with much more care. Despite that, they had no knowledge about the nutritional value of the water. Excessive application of chemical fertilisers therefore appeared to be common practice. Our information made clear that a better understanding of treated sewagewater as a production factor in farming should form the core of all our work.

8.2 Farmers' objectives and priorities

The facilitator, being an extension officer or researcher, gets together with farmers that want to change their farming practices. They try to find all general objectives relevant to these practices. According to Vereijken (1996), Kabourakis (1996), and Da Silva (1999) farmers tend to select the same set of general objectives:

- Basic income and profit;
- Food supply;
- Abiotic environment;
- Health and well-being;
- Nature and landscape;
- Employment.

The relative priority according to each general objective, however, varies from country to country, from countryside to countryside and even from farmer to farmer. It is likely that regional stakeholders in Jordan (e.g. professionals, government employees, international organisations and NGO's) will ask for a ranking of objectives different to that of the farmers. Table 8.1 shows the likely difference.

Table 8.1 Ranking of general objectives according to farmers and according to other stakeholders in zones A, B, and C. Note that rankings conflict with each other, but society expects farmers to solve problems concerning food quality and the environment. The tension between farmers and regional stakeholders thus increases.

Farmers' choice			Stakeholders' choice
Zone A	Zone B	Zone C	
1. Basic income and profit	1. Basic income and profit	1. Basic income and profit	1. Abiotic environment
2. Food supply	2. Health and well-being	2. Food supply	2. Health and well-being
3. Health and well-being	3. Food supply	3. Abiotic environment	3. Food supply
4. Abiotic environment	4. Abiotic environment	4. Health and well-being	4. Basic income and profit
5. Nature and landscape	5. Nature and landscape	5. Nature and landscape	5. Nature and landscape
6. Employment	6. Employment	6. Employment	6. Employment

But, despite this difference, the literature demonstrates that while following their own goals, the farmers should also work on those of other stakeholders at the same time (Kabourakis, 1996; Leeuwis, 1999). There is in any case no other road, as only farmers can be called upon with regard to the management of their natural resources. Other stakeholders are in this sense no more than interest groups, without possibilities for the effective management of their surroundings. As long as we help the farmer to guarantee profitable farm production the farmer will always do his utmost to address socio-environmental issues as well (Simon, 1996).

Moreover, general objectives are not applicable to everyday farming practices. We have to quantify them somehow. Only quantified targets are useful for redesigning farming systems (Vereijken, 1994). In order to be able to do so we should translate each general objective into concrete criteria and standards, thus providing useful specifications that allow further quantification. We refer to this process of translating general objectives into quantified standards as 'parameterisation'. Table 8.2 gives an example.

Table 8.2 Parameterisation of the general objective concerning the objective of income and profit.

Entity	**Example**
General objective	Income or profit
Criteria (specified objectives)	Money per month
Standard	JD 200 per month

At this stage farmers are invited to initiate discussion about the possible translation of all general objectives that they provided during their initial meeting. They have to find at least three specifications on which they may focus further parameterisation. Table 8.3 gives the results, for farmers in zones A, B, and C and is explained as follows:

Table 8.3 Parameterisation of the general objectives in criteria theoretically presumed for regional stakeholders and farmers in zones A, B, and C. The dimensions given here are not exhaustive or limited to the ones that are indicated. Discussion between farmers and facilitator may result in many other relevant criteria or dimensions. However, for the present stage of their development, the presented criteria supports their interests. The final result is a matter of creativity: of local demands and of farmers' experiences. Specifications should also be ranked according to group.

General objective for regional stakeholders	**Specific objective for regional stakeholders**
1. Abiotic Environment	1.1 Water (grams of residues* / litre)
	1.2 Soil (grams of residues / kg of soil)
	1.3 Air (grams of residues / volume unit)
2. Health/Well-being	2.1 Rural people (cost for medical care / person)
	2.2 Urban people
	2.3 Farm animals
3. Food Supply	3.1 Quality (% of the price that a commodity of the best quality obtained at the market)
	3.2 Sustainability (costs for external inputs / costs for internal inputs)
	3.3 Quantity (kg / ha)
	3.4 Stability (kg / ha / season is constant)
	3.5 Accessibility (institutional budgets for solving farmers' problems in money / farmer)
4. Basic Income/Profit	4.1 Farm level (money / time unit / farm)
	4.2 Regional level (money / time unit / co-operation)
	4.3 National level (money / time unit / production sector)
5. Nature/Landscape	5.1 Flora (number of plant species / unit of land)
	5.2 Fauna (number of animal species / unit of land)
	5.3 Landscape (number of connected ecosystems)
6. Employment	6.1 Farm level (labour hours / man / time unit)
	6.2 Regional level (labour hours / co-operation / time unit)
	6.3 National level (labour hours / production sector / time unit)

General objective for farmers in zone A	**Specific objective for farmers in zone A**
1. Basic Income/Profit	1.1 Farm level (money / time unit / farm)
	1.2 Regional level (money / time unit / co-operation)
	1.3 National level (money / time unit / production sector)
2. Food Supply	2.1 Quantity (kg / ha)
	2.2 Quality (% of the price that a commodity of the best quality obtained at the market)
	2.3 Sustainability (costs for external inputs / costs for internal inputs)
	2.4 Stability (kg / ha / season is constant)
	2.5 Accessibility (institutional budgets for solving farmers' problems in money / farmer)
3. Health/Well-being	3.1 Rural people (cost for medical care / person)
	3.2 Urban people
	3.3 Farm animals
4. Abiotic Environment	4.1 Water (grams of residues / litre)
	4.2 Soil (grams of residues / kg of soil)
	4.3 Air (grams of residues / volume unit)
5. Nature/Landscape	5.1 Flora (number of plant species / unit of land)
	5.2 Fauna (number of animal species / unit of land)
	5.3 Landscape (number of connected ecosystems)
6. Employment	6.1 Farm level (labour hours / man / time unit)
	6.2 Regional level (labour hours / co-operation / time unit)
	6.3 National level (labour hours / production sector / time unit)

General objective for farmers in zone B	Specific objective for farmers in zone B
1. Basic Income/Profit	1.1 Farm level (money / time unit / farm)
	1.2 Regional level (money / time unit / co-operation)
	1.3 National level (money / time unit / production sector)
2. Health/Well-being	2.1 Rural people (cost for medical care / person)
	2.2 Urban people
	2.3 Farm animals
3. Food Supply	3.1 Quantity (kg / ha)
	3.2 Sustainability (costs for external inputs / costs for internal inputs)
	3.3 Quality (% of the price that a commodity of the best quality obtained at the market)
	3.4 Stability (kg / ha / season is constant)
	3.5 Accessibility (institutional budgets for solving farmers' problems in money / farmer)
4. Abiotic Environment	4.1 Water (grams of residues / litre)
	4.2 Soil (grams of residues / kg of soil)
	4.3 Air (grams of residues / volume unit)
5. Nature/Landscape	5.1 Flora (number of plant species / unit of land)
	5.2 Fauna (number of animal species / unit of land)
	5.3 Landscape (number of connected ecosystems)
6. Employment	6.1 Farm level (labour hours / man / time unit)
	6.2 Regional level (labour hours / co-operation / time unit)
	6.3 National level (labour hours / production sector / time unit)

General objective for farmers in zone C	Specific objective for farmers in zone C
1. Basic Income/Profit	1.1 Farm level (money / time unit / farm)
	1.2 Regional level (money / time unit / co-operation)
	1.3 National level (money / time unit / production sector)
2. Food Supply	2.1 Quality (% of the price that a commodity of the best quality obtained at the market)
	2.2 Sustainability (costs for external inputs / costs for internal inputs)
	2.3 Quantity (kg / ha)
	2.4 Stability (kg / ha / season is constant)
	2.5 Accessibility (institutional budgets for solving farmers' problems in money / farmer)
3. Abiotic Environment	3.1 Water (grams of residues / litre)
	3.1 Soil (grams of residues / kg of soil)
	3.3 Air (grams of residues / volume unit)
4. Health/Well-being	4.1 Rural people (cost for medical care / person)
	4.2 Urban people
	4.3 Farm animals
5. Nature/Landscape	5.1 Flora (number of plant species / unit of land)
	5.2 Fauna (number of animal species / unit of land)
	5.3 Landscape (number of connected ecosystems)
6. Employment	6.1 Farm level (labour hours / man / time unit)
	6.2 Regional level (labour hours / co-operation / time unit)
	6.3 National level (labour hours / production sector / time unit)

* residue either chemical or biological residue

Abiotic Environment: Priority is given to the reduction of emissions of N, P, and K to the abiotic environment. The focus is on water, both surface and ground water, especially against nitrate leaching, which became a serious problem in this region because of high N inputs from treated sewagewater and chemical fertilisers. Soil is also considered (accumulation of nutrients). Integrated irrigation practices and nutrient management strategies, including progressive exclusion of over-irrigation with treated sewagewater (high nutrient content especially N) and excessive use of chemical fertilisers, will alleviate the pressure on the abiotic environment with less pollution of water and soil (minimise environment's exposure to nutrients by reducing the leaching and accumulation of nutrients). As a result, fertiliser inputs will be reduced and an efficient integrated nutrient management will be applied to achieve a balance between agronomically desired, ecologically acceptable nutrient reserves in the soil and nutrients present in treated sewagewater. Balancing soil nutrient reserves and nutrient inputs in treated sewagewater to match crop requirements and crop uptake is of great importance in limiting potential risks of nutrient leaching. It is important to keep in mind that inputs of nutrients can only be reduced to a certain extent for environmental benefits, because an economic level of production must be maintained.

Health/Well-being: The two main components of treated sewagewater related to public health are pathogenic organisms and hazardous chemicals. Pathogenic organisms (viruses, bacteria, protozoa and helminth's egg) may be associated with the transmission of diseases to farm workers and other people, and to livestock exposed to treated sewagewater either by incidental physical contact or by consuming crops irrigated with treated sewagewater. Hazardous chemicals may reach ground water or surface water, or contaminate crops. Diseases may be transmitted to humans by the handling or consumption of contaminated crops. Important factors in this regard are the persistence of pathogens on crops at the time they are consumed by humans or animals and the persistence of pathogens in the soil and water. Sunlight exerts a lethal effect on all micro-organisms involved in soil surface or plant contamination, so a suitable time interval has to be maintained between irrigation with treated sewagewater and grazing or crop handling. Filtration, adsorption and sedimentation processes taking place in soils make its matrix an efficient medium for eliminating bacteria, helminth's egg and protozoan cysts and confine them to the top few centimetres of the soil surface layer, so they never reach ground water. Using irrigation systems that reduce the direct contact of farmers or labourers with treated sewagewater is recommended, like drip or subsurface drip irrigation. In case of sprinkler or spray irrigation an appropriate buffer zone (generally 100-500m) is recommended and in case of surface irrigation, where there is a risk of direct contamination of farmers and farm employees resulting primarily from improper personal hygiene and walking barefoot on wet ground, it is recommended to wear shoes when entering irrigated areas with treated sewagewater.

Basic Income/Profit: Basic income/profit will be based on efficient production of high quality products to be optimised within the regional markets. To maintain the farmers in the region, income and profit must remain attractive, to prevent the farmers from leaving the land for a job in the city. Therefore, production costs are to be minimised and production benefits are to be maximised in order to make the prototype more competitive than the current farming system. Basic income/profit is mainly supported by reducing costs of chemical fertilisers added by managing nutrients in treated sewagewater, and reducing costs of irrigation water pumping by reducing irrigation intervals, to match crop water requirements throughout the growing season. Maintenance of income at farm level is of prime importance but is based on efficient production and farming according to good agricultural practices and standards, to protect the environment.

Food Supply: Focuses on optimum balance between quality and quantity, as a basis for basic income/profit, and health/well-being. The balance between quality and quantity requires nutrient management to maintain soil fertility and to stabilise farm production. Quality of produce is considered to be more important for achieving an appropriate farm income than quantity of produce, given the strong competition in regional markets.

Nature/Landscape and Employment: Improvements to nature/landscape and employment are considered as being sufficiently covered by the improvements in the foregoing objectives.

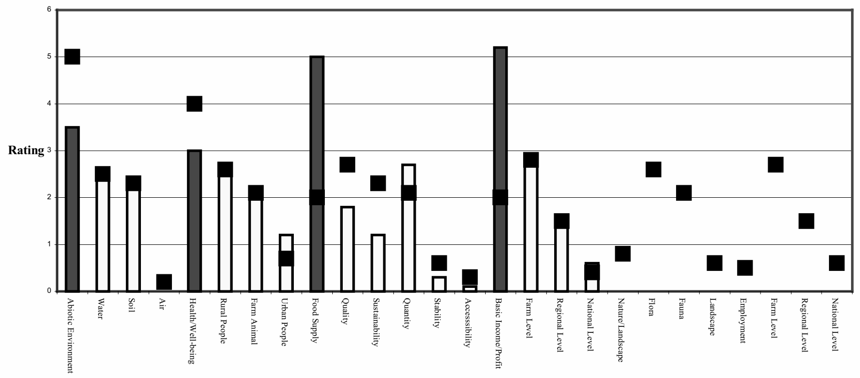
Ranking of general or specified objectives can be done per farmer (individual basis), but also according to group (regional basis). In the latter case, we have to average the results of all individual farmers per production zone. By then, each farmer can compare his own preferences with the average of those of regional colleagues. The results obtained by all participating farmers should finally be brought together and discussed in meetings. Resulting discussions help farmers to get a better understanding of their own preferences and of those of their colleagues. This is an essential step for the whole conversion process. Figure 8.1 shows a diagrammatic presentation of the results of a concerted action for acquiring insights into the objectives of farmers in zones A, B, and C. Only farmers' views are presented, since the aim of the research is to design a theoretical prototype for the end users, who are the farmers, though the views of the regional stakeholders are presented as squares in the figures to show existing differences in perception.

The list of demands, identified with the method discussed earlier, will result in more than twenty objectives (see table 8.3). Close observation may reveal that some objectives reinforce each other while others are in conflict. Moreover, it is not advisable to design with so many demands in one round. Vereijken (1995) and Kabourakis (1996) therefore advise asking participating farmers to select their ten most important objectives out of the twenty or more that they have already identified. Table 8.4 shows the results when the question was raised for farmers in zones A, B, and C.

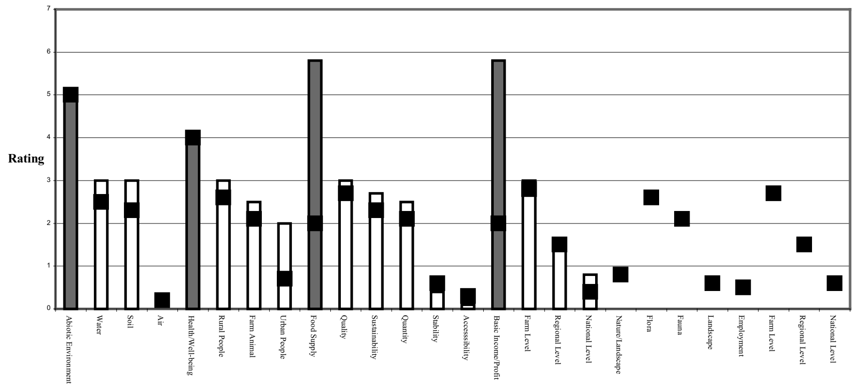
In conclusion, prototyping of innovative farming systems using treated sewagewater in irrigation according to the methodology of Vereijken, strongly advocated by Goewie (1995), Ugas (1995) and Kabourakis (1996), seems a promising way to create farms that meet future standards as set by the expectations of society at large for agricultural production. This methodology starts by identifying the objectives of the new farming system to be achieved in the future. Here, the new farming system depends on using treated sewagewater as a source of irrigation water and nutrients, especially Nitrogen (N), Phosphorus (P) and Potassium (K). A diagnosis of the existing situation of treated sewagewater use was made first. Besides this, the targeted contribution of the designed prototype in improving the use of treated sewagewater in the long term in the area will be determined. Therefore, the diagnosis and ranking of objectives should be done in collaboration with the major actors involved in treated sewagewater use, and after careful examination of all available resources, agro-technology, experiences and knowledge.

Table 8.4 Ranking of the ten most important specified objectives for farmers in zone A, B, and C.

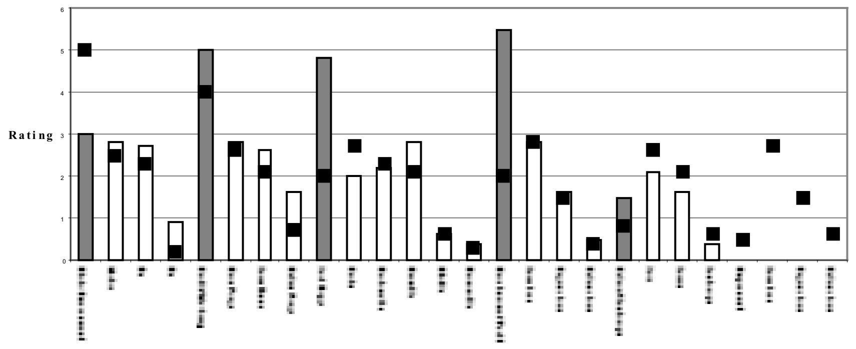
Zone A		
1. Basic Income / Profit- Farm Level	1. Basic Income / Profit- Farm Level	1. Basic Income / Profit- Farm Level
2. Food Supply- Quantity	2. Health/Well-being- Rural People	2. Abiotic Environment- Water
3. Abiotic Environment- Water	3. Food Supply- Quantity	3. Abiotic Environment- Soil
4. Food Supply- Quality	4. Health/Well-being- Farm Animals	4. Food Supply- Quality
5. Abiotic Environment- Soil	9. Food Supply- Sustainability	5. Food Supply- Sustainability
6. Health/Well-being- Rural People	6. Food Supply- Quality	6. Food Supply- Quantity
7. Basic Income/Profit- Regional Level	7. Basic Income/Profit- Regional Level	7. Health/Well-being- Rural People
8. Health/Well-being- Farm Animals	8. Abiotic Environment- Water	8. Health/Well-being- Farm Animals
9. Food Supply- Sustainability	9. Abiotic Environment- Soil	9. Basic Income/Profit- Regional Level
10. Health/Well-being- Urban People	10. Health/Well-being- Urban People	10. Health/Well-being- Urban People



General and Specific Objectives ranked presentation for farmers in zone A



General and Specific Objectives ranked presentation for farmers in zone B



General and Specific Objectives ranked presentation for farmers in zone C

Figure 8.1 Diagrammatic presentations of ranked general and specific objectives. The black vertical bars indicate farmers' preferences for the six general objectives. The longer the bar the higher its appreciation by the farmers. The white bars indicate farmers' preferences for specific objectives. Ranking between specified objectives happened within the general objective. The squares indicate the average of all regional stakeholder appreciations together. Only farmers' views are presented, since the aim of the research is to design a theoretical prototype for the end users, who are the farmers, though the views of the regional stakeholders are presented as squares in the figures to show existing differences in perception.

8.3 Quantification of objectives into parameters

The next step, after farmers and regional stakeholders had identified their ten most important objectives for the time being, was to start with the process of quantification of the specific objectives. This means that the objectives have to be expressed in parameters that can be used as targets to evaluate the prototype's performance. This process is a creative and educational one, because through prototype designing the selection of one parameter over another is a changing process. The researcher has to do his best to stimulate farmers and regional stakeholders to select a suitable parameter that can serve more than only one objective (multi-objective parameter). The selection of the parameters is a risky process in itself because, at the beginning, many of them are quantified as better than the situation as actually confronted. To test the validity of these parameters and ensure applicability of the new farming system, the prototype has to be tested repeatedly on actual farms with the support of scientific knowledge and farmer experiences. Table 8.5 provides the parameters that have been selected by all the participants. A conceptual definition of these parameters is as follows:

- Macro-nutrient Balance (MB)

The ratio between macro-nutrients added to the plant (inputs) to macro-nutrients removed by the plant (outputs) (MB = 1).
For the quantification of the annual ratios between inputs and outputs of the major plant nutrients (nitrogen (N), phosphorus (P) and potassium (K)), a range has to be established according to what is agronomically desired and environmentally acceptable. A balance between what will be added to the plant (nutrients in treated sewagewater, fertilisers) and what will be taken by the plant (plant growth, harvests) should be achieved. The objectives that will be quantified by MB are:
basic income/profitability (through gradual reduction of chemical fertiliser application);
food supply - sustainability (through providing an optimum range of major nutrients in soil and plant by depending on organic fertilisers); and
abiotic environment - water and soil (through reduction of contaminant applications to soil, surface water and ground water).

- Net Surplus (NS)

Value of yield minus all costs (NS>1)
Costs of chemical fertilisers and water are the most important parameters at this stage of the project. Other costs like machinery, equipment, field workers, and plant protection are kept as fixed costs that will not be changed before or after the application of the prototypes. This

parameter will quantify basic income / profitability (reducing the costs, through reduction in use of chemical fertilisers and over-irrigation will increase the profitability of the farm).

- Irrigation Index (II)

The ratio of the amount of water delivered to the plant in comparison with the desired amount of water needed by the plant for optimum plant growth (II ≤ 1).

This parameter quantifies objectives in:

- basic income / profit (through expenses paid in securing enough water);
- food supply - sustainability (increasing the efficiencies in irrigation schemes will increase the sustainability of the schemes by providing enough water for plant growth from year to year, an important issue as water is a scarce commodity in Jordan); and
- abiotic environment (higher efficiencies will reduce the contamination of water and soil by excessive amounts of nutrients, such as nitrate contamination of ground water).

- Soil Salinity Index (SSI)

The agronomically desired and environmentally acceptable range of soil salinity or soil electrical conductivity (EC_e) for plant growth.

In the long term strategy, the total amount of salt added to the soil through irrigation (salt in) and the rate of salt removal by leaching and plant uptake (salt out) should be in equilibrium within the desired range. This parameter quantifies objectives in:

- basic income/profit (through increasing the productivity of the plant and consequently the overall production of the farm);
- food supply - quantity and sustainability (maintaining the EC_e within the desired range will have a great influence in protecting the soil from salinisation and keep it productive); and
- abiotic environment – water and soil (increasing salts added to the soil profile will cause soil salinisation and consequently ground water salinisation).

- Organic Matter Balances (OMB)

The ratio between OM added to the plant (treated sewage, manure, plant residue) and OM removed by the plant (plant growth, harvests) (OM inputs / OM outputs, OMB > x).

OM addition is effected by the humification coefficient. At this stage of the research, the humification coefficient was not calculated and no literature found that provided a calculation of this coefficient in the study area, so this parameter was not tested at this stage. OMB is a central point in agricultural productivity and provides a quantified objective for food supply – sustainability and quantity, and abiotic environment – and soil.

- Human, Animal and Environmental Exposure to Sewagewater (HESW, AESW, EESW)

The way the environment (water, soil and crop), human (farmer, worker and consumer) and animals are exposed to treated sewagewater through irrigation and crop consumption in areas irrigated by treated sewagewater.
Sewagewater treatment was considered, in the past, as the only effective measure to reduce the risks to the environment and human when treated sewagewater was being used in irrigated agriculture. But this is not the case all the time. In Jordan, the As Samra treatment plant is overloaded and the plant performance is below expectation. This will cause a serious problem to the environment and humans. Other measures must be applied to reduce this risk, such as crop restriction, choice of irrigation methods and control of human exposure to treated sewagewater and hygiene. Because of time limitations, laboratory analysis and my background not being in the field of disease and hygiene, these parameters were not tested at this stage of the research. It is recommended to incorporate, at the next stage, a person qualified in diseases and hygiene to test these parameters. These parameters quantify objectives in abiotic environment and health / well being.

- Macro-nutrient Leaf Reserve (MLR)

The agronomic desired ranges of Nitrogen Leaf Reserve (NLR), Phosphorus Leaf Reserve (PLR) and Potassium Leaf Reserve (KLR). For desired ranges see Appendix 8.1.
This parameter quantifies the objective of the abiotic environment – water and soil (because of reduced contamination).

- Macro-nutrient Soil Reserve (MSL)

The agronomic desired and environmentally acceptable ranges of Nitrogen Soil Reserve (NSR), Phosphorus Soil Reserve (PSR) and Potassium Soil Reserve (KSR). For desired ranges see Appendix 8.2.
This parameter quantifies the objective of the abiotic environment – water and soil (because of reduced contamination).

- Quality Production Index (QPI)

A comprehensive parameter of quality and quantity of the production of single crops.
The decrease in the use of chemical fertilisers by incorporating nutrients in treated sewagewater in crop fertilisation strategy, and reduction in water application to crops to match crop water requirements, must not effect the quality and quantity of crop production. This parameter tests this by quantifying the objective of food supply – quality and quantity.

Table 8.5 Provisional list of parameters according to the interest of regional stakeholders and farmers in the study area. This table shows that one parameter can quantify more than one objective, and indicates the number of participants interested in each parameter.

Order	**Parameters**	**Definition**	**Objectives covered***	**Participants interested**
1	MB (Macro-nutrient Balances)	Ratio between MB inputs / MB outputs	1,2,5,7,9	14
		(MB inputs / MB outputs < x)	5,9	
2	NS (Net Surplus)	Yield minus all costs, including cost minimisation through using nutrients in treated sewagewater. (NS > 0)		12
3	II (Irrigation Index)	Ratio between amount of irrigation water used and desired amount of irrigation water. (II ≤ 1)	1,2,5,7,9	11
4	SSI (Soil Salinity Index)	Agronomic desired and environmentally acceptable range of soil salinity (x < ECe < y)	1,2,5,7,8,9	11
5	OMB (Organic Matter Balances)	Ratio between OM inputs / OM outputs (OMB > x)	2,7,8	10
6	EESW (Environment Exposure to Sewagewater)	Annual exposure of environment (soil, surface water, groundwater, crops) to treated sewagewater through irrigation	1,2	8
7	MLR (Macro-nutrients Leaf Reserve)	Agronomically desired range of micro-nutrients in leaves of crops grown. (x < MLR < y)	1,2	8
8	MSR (Macro-nutrients Soil Reserves)	Agronomically desired and environmentally acceptable range of micro-nutrients in soil reserve. (x < MSR < y)	1,2	8
9	QPI (Quality Production Index)	Comprehensive parameters of quality and quantity of crop production. (0 < QPI > 1)	6,8	6
10	HESW (Human Exposure to Sewagewater)	Annual human exposure (farmers, labours, consumers) to treated sewagewater through irrigation practices.	3,10	5
11	AESW (Animal Exposure to Sewagewater)	Annual farm animals exposure to treated sewagewater.	4	5

* See table 8.4 for specification

In conclusion, transformation of the objectives into appropriate parameters is the second step in the procedure for prototyping farms that use treated sewage in irrigation. It is based on the careful examination and selection of parameters related to the objectives and the production system, and determines the quantification of the objectives of treated sewage use in irrigation. Consequently, if the parameters are not correctly selected and quantified, the objectives are not evaluated according to whether the objectives of treated sewagewater use in irrigation have been met. Neither will it be possible to test treated sewagewater use in irrigation prototypes in practice. The selection of the parameters should therefore be done after careful examination of the objectives and the production system. The criterion of being integrated or being indispensable for a single objective was used for the parameter selection. In this way the quantified objectives could be used as desired results, to evaluate the achieved results of treated sewagewater use in irrigation prototypes. The prototypes are tested and improved until the results achieved match the desired ones.

8.4 Identification of relevant farming methods and techniques

After the quantification of objectives into parameters, the following step is the identification of a suitable set of methods and techniques. This step is a creative one in which all the participants did their best to integrate potentially conflicting objectives in farming methods and techniques, in order to bridge the gaps between these objectives. In doing so the farmers start to feel that they are really involved in the designing process and appreciative of the fact that their skills are taken seriously. The farmers found that one farming method could fulfil more than one parameter at the same time, and this made them feel that they were starting to do something by themselves.

In view of this, three multi-objective farming methods (Table 8.6) are proposed to achieve the major 10 objectives quantified by 11 parameters (Table 8.7). A description of the three farming methods is provided below. The description of each multi-objective farming method will be done at three levels: definition, design for practical application and research requirements.

Table 8.6 Provisional list of methods, used in the prototyping of treated sewagewater use in the study area, according to interests of participants. The participants selected only three farming methods because at this stage of the research were interested in water issues like nutrients in the treated sewagewater and quantities of irrigation water applied to the field. In later stages participants may identify other farming methods as new interests appear.

Order	**Methods**	**Definition**	**Objectives covered***	**Participants interested**
1	NM (Nutrient Management)	Development and maintenance of agronomically desired and environmentally acceptable range of leaf and soil reserves of macro-nutrients and macro-nutrients balances to sustain quality production with minimum external inputs (fertilisers), primarily through recycling of nutrients in treated sewagewater.	1,2,3,5,6,7,8,9	14
2	WM (Water Management)	Optimum use of treated sewagewater as a source of irrigation water and its management, without wasting water and maintaining or improving farm income.	1,2,3,4,6,7,8,10	11
3	FSO (Farm Structure Optimisation)	Achievement and maintenance of a net surplus > 0, taking into account yields, costs and fertiliser inputs achieved in the treated sewagewater use in irrigation prototyping.	5,9	8

See table 8.4 for specification

Table 8.7 Farmers involved are considered to be those who want to create a new farming system. The left column shows the ranking of the ten most important targets which farmers are going to realise at their farms during the transition period of the project concerned. The column in the middle provides the quantification of the targets involved. The right column indicates relevant farming methods that might fulfil the targets. Farmers, supported by the researcher, must provide the targets, the quantification and the methods.

Ranked specific objectives in Zone A	Possible quantification in multi-objective parameters (criteria)	Farming methods that support achievement of the targets
1. Basic Income/Profit Farm Level	1.1 NS 1.2 MB	FSO, NM
2. Food Supply Quantity	2.1 SSI 2.2 OMB 2.3 QPI	NM, WM
3. Abiotic Environment Water	3.1 see 1.2, 2.1 3.2 II 3.3 EESW 3.4 NLR, PLR, KLR 3.5 NSR, PSR, KSR	NM, WM
4. Food Supply-Quality	4.1 2.3	NM, WM
5. Abiotic Environment Soil	5.1 see 1.2, 2.1, 3.2, 3.3, 3.4, 3.5	NM, WM
6. Health/Well-being Rural People	6.1 HESW	WM
7. Basic Income/Profit Regional Level	7.1 see 1.1, 1.2, 2.1, 3.2	FSO, NM
8. Health/Well-being Farm Animals	8.1 AESW	WM
9. Food Supply Sustainability	9.1 see 1.2, 2.1, 2.2, 3.2	NM, WM
10. Health/Well-being Urban People	10.1see 6.1	WM

Ranked specific objectives in Zone B	Possible quantification in multi-objective parameters (criteria)	Farming methods that support achievement of the targets
1. Basic Income/Profit Farm Level	1.1 NS 1.2 MB	FSO, NM
2. Health/Well-being-Rural People	2.1 HESW	WM
3. Food Supply-Quantity	3.1 SSI 3.2 OMB 3.3 QPI	NM, WM
4. Health/Well-being-Farm Animals	4.1 AESW	WM
5. Food Supply-Sustainability	see 1.2, 3.1, 3.2 5.2 II	NM, WM
6. Food Supply-Quality	6.1 see 3.3	NM, WM
7. Basic Income/Profit-Regional Level	7.1 see 1.1, 1.2, 3.1, 5.2	FSO
8. Abiotic Environment-Water	8.1 see 1.2, 3.1, 5.2 8.2 EESW 8.3 NLR, PLR, KLR 8.4 NSR, PSR, KSR	NM, WM
9. Abiotic Environment-Soil	9.1 see 1.2, 3.1, 5.2, 8.2, 8.3, 8.4	NM, WM
10. Health/Well-being-Urban People	10.1see 2.1	WM

Ranked specific objectives in Zone C	Possible quantification in multi-objective parameters (criteria)	Farming methods that support achievement of the targets
1. Basic Income/Profit-Farm Level	1.1 NS 1.2 MB	FSO
2. Abiotic Environment-Water	2.1 see 1.2 2.2 II 2.3 EESW 2.4 SSI 2.5 NLR, PLR, KLR 2.6 NSR, PSR, KSR	NM, WM
3. Abiotic Environment-Soil	3.1 see 1.2, 2.2, 2.3, 2.4, 2.5, 2.6	NM, WM
4. Food Supply-Quality	4.1 QPI	NM, WM
5. Food Supply-Sustainability	see 1.2, 2.2, 2.4 5.2 OMB	NM,WM
6. Food Supply-Quantity	6.1 see 2.4, 4.1, 5.2	NM, WM
7. Health/Well-being-Rural People	7.1 HESW	WM
8. Health/Well-being-Farm Animals	8.1 AESW	WM
9. Basic Income/Profit-Regional Level	9.1 see 1.1, 1.2, 2.2, 2.4	FSO
10. Health/Well-being-Urban People	10.1see 7.1	WM

8.4.1 Nutrient Management (NM)

Definition

In Nutrient Management (NM) most of the nutrients will be derived from organic materials (treated sewagewater and manure). If this is not sufficient for the plant need chemical fertilisers will supplement it. Nutrient Management (NM) aims to create sustainable soil fertility (physically, chemically and biologically) with minimum external inputs (chemical fertilisers) and minimum expenses. It sustains the Quality Production Index (QPI) by preserving chemical soil fertility through tuning inputs of nutrients to outputs, in order to achieve and maintain agronomically desired and environmentally acceptable soil reserves.

Design

The general design of Nutrient Management (NM) involves the assessment of the available Nitrogen Leaf Reserves (NLR), Phosphorus Leaf Reserves (PLR), Potassium Leaf Reserves

(KLR), Nitrogen Soil Reserves (NSR), Phosphorus Soil Reserves (PSR), Potassium Soil Reserves (KSR), and Organic Matter Content (OMC).

Agronomically undesirable	<	Desired range	<	Ecologically undesirable
Input > output		Input = output		Input < output

Nutrient management to be followed (Vereijken, 1995)

Firstly, the farmers should estimate the nutrient outputs as the expected output (tonne/ha) of each crop they grow multiplied by their nutrient content. Secondly, they should estimate the nitrogen, phosphorus and potassium requirements of each crop from plant and soil reserve analyses. They should then take into consideration the nitrogen, phosphorus and potassium content in the treated sewagewater and choose the most appropriate type of animal manure, with nitrogen, phosphorus and potassium ratio optimally covering the nitrogen, phosphorus and potassium ratio required for each crop. If this amount does not cover the nitrogen, phosphorus and potassium needs, additional chemical fertiliser can be applied. All the above activity is done by farmers and the researcher together, because farmers still do not have experience in determining how much nutrients they need to add to crops, based on the analysis of water, plant and soil.

The expectation is that in the first year of the conversion, the farmers would still rely on chemical fertilisers and that therefore the above recommendations will not be carried out with rigorous precision. In this case the Nutrient Management (NM) is slightly disturbed, and this should be taken into consideration in the following year. After the growing season the researcher should recalculate and evaluate the Nutrient Management (NM), considering the effect of any changes brought about.

Research requirements

The nutrient outflow as determined by calculating the amount of nutrients in the water (treated sewagewater), chemical fertilisers and manure. The amount of nitrogen (N), phosphorous (P) and potassium (K) in the water used to irrigate crops was measured weekly on the selected farms. These figures on nutrient concentration, combined with data on frequency and duration of irrigation, gave an indication of the water use on the farm and the nutrient inflow through the treated sewagewater. By counting the chemical fertiliser bags, registration of the kind of chemical fertiliser used and the frequency of chemical fertiliser application, an indication of the nutrient inflow through chemical fertilisers was obtained. In order to give an indication of the nutrient inflow through manure, the amount and kind of manure used needed to be known. Literature provided figures on the nutrient content of specific kinds of manure. The amount used was estimated through counting bags and converting volume units used by farmers.

- The nutrient outflow was only measured in crops. The amount of nitrogen (N), phosphorus (P) and potassium (K) in the crops was measured through plant sampling and analysis at, or around, harvest time. The figures in nutrient concentrations, combined with yield figures, gave an indication of the nutrient outflow through harvested plant parts.
- The nutrient accumulation/degradation (or in fact the nutrient presence) was identified. The amount of nitrogen (N), phosphorus (P) and potassium (K) in the soil was measured through soil sampling. The figures on nutrient concentrations, combined with data about particular areas and rooting depth, gave an indication of the nutrient presence in the soil.

8.4.2 Water Management (WM)

Definition

Water Management (WM) is the practice of irrigating crops without wasting water and electricity while maintaining or improving farm income. Depending on farm characteristics (soils, type of irrigation system, cropping patterns, land and water availability, costs and crop prices), Water Management (WM) can take different approaches:

- Eliminate excess water and electricity use while maintaining maximum crop yield.
- Reduce irrigation water use to maximise net returns per hectare.
- Reallocate saved water to maximise farm income.

Figure 8.2 shows how irrigation water impacts upon crop yields. Yields increase rapidly as more water is applied, but only up to a point. The rate of increase then slows down, and after reaching the point of maximum yield it begins to decrease. Water applied to crops beyond the maximum yield point is wasted water.

Figure 8.3 shows that at the point of maximum yield (point B), crop revenues have levelled off and eventually begin to fall, while costs are still rising. Thus, any water use beyond the maximum yield point will result in reduced net income. In some situations and with some crops, water use can be reduced to below maximum yield point without reducing profits and may, in fact, increase profits. The water and energy saved by going from point B to point A could be used to irrigate other fields on the farm.

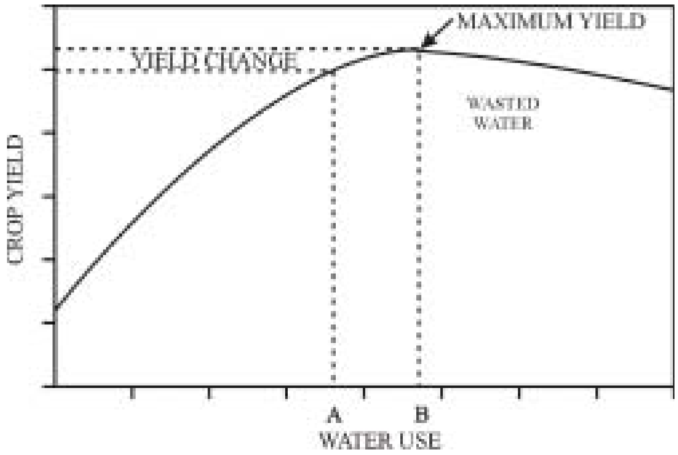


Figure 8.2 Crop yield and water use relationship (BPA, 1988)

During the past three years (1999 to 2001), the research studied and documented irrigation practices for farmers in Seil Al Zarqa and the Middle Jordan Valley. The research shows that farmers practised three levels of irrigation management:

- Over-irrigating and wasting water.
- Fully irrigating to maximise yields.
- Partially irrigating to maximise income per hectare.

From Figure 8.3 the over-irrigated farms could have shown positive net returns by reducing water use to the full irrigation level, that is, by eliminating waste. If water use were reduced to slightly below the yield maximising point, profits would increase. Figure 8.3 indicates the following important points:

- Over-irrigation reduces net income.
- Net income can be increased by a small reduction in water use below the full irrigation level.
- Farm profits may be increased even when per-hectare profits are reduced, if the water saved by partial irrigation is used to irrigate additional land (However, low crop prices may preclude this option).

Design

Water Management (WM) is the implementation of good farm management practices, and growers should set up an information base to properly schedule irrigation water application. Practicing effective Water Management (WM) requires knowledge and information about:

- Farm characteristics, types of soil and their moisture-holding capacity.
- Crop Water Requirement, both the timing and rate of water application relative to plant growth.
- Weather variability, rainfall and factors influencing evaporation and transpiration.

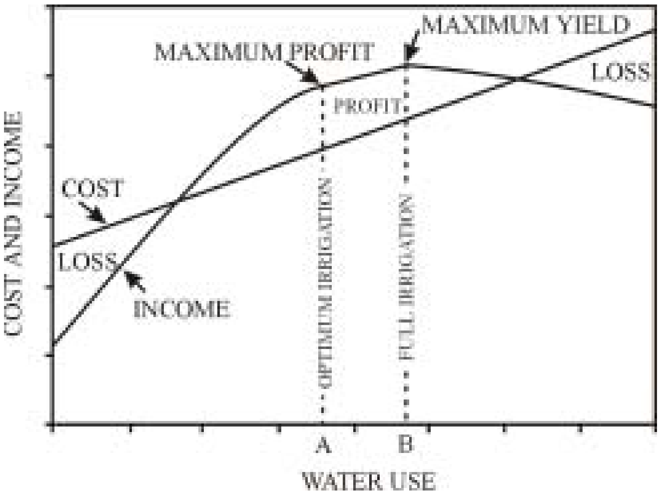


Figure 8.3 Crop production cost and income, profit and loss (BPA, 1988)

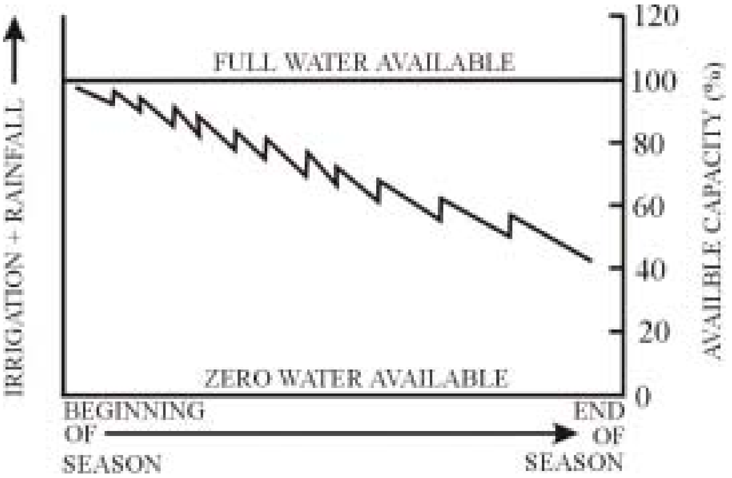


Figure 8.4 Changes in soil moisture levels (BPA, 1988)

The theory behind Water Management (WM) is that with careful irrigation scheduling, the total water application should be slightly less than the total water use of the plant during the growing season. As shown in Figure 8.4, soil moisture will gradually decrease over the season, but is somewhat replenished with each irrigation. It is important not to irrigate beyond the full available water capacity of the soil, but also not to under-irrigate to the point where zero water is available to the plant (wilting point). Water Management (WM) implies not only the proper rate and amount of irrigation, but also the proper timing relative to the growth stage of the plant.

The Water Management (WM) method must be compatible with the entire crop production in the study area, especially Nutrient Management (NM). Current crop production in the study area depends on irrigation to increase yields by stimulating crop growth, fruit induction as well as fruit-size, and by preventing the shrivelling of fruits.

Practically all the crops in Seil Al Zarqa are irrigated by surface irrigation (Border irrigation) and in the Middle Jordan Valley the crops are irrigated by drip irrigation. The water is applied to crops in both areas without considering the water requirement (seasonal deficit) of the crops or evapotranspiration. The required cultural practices for treated sewage use in irrigation as a source of nutrients is described in Nutrient Management (NM). Water application either through surface irrigation or drip irrigation must be adjusted regarding the total amount of water to be applied per area/season, the dosage and the timing of applications. Farmers should make an irrigation plan, estimating the crop water requirements, the amount and frequency of irrigation water, based on the average potential (reference) evapotranspiration. An irrigation plan for the whole period without sufficient precipitation should be done using the CROPWAT computer programme (Smith, 1992).

The timing of irrigation will be based on the use of tensiometers. Irrigation is preferably done late in the afternoon or very early in the morning to minimise water losses. In addition, frequent irrigation with small amounts of water is preferable to irrigation of longer periods with large amounts of water because water losses will be minimised.

Excessive irrigation may provoke crop diseases and loss of nutrients. Excessive amount of water in the soil stimulates migration of the nitrate nitrogen and phosphorus below the root zone of the crops. Nutrients are thus unavailable for crops and may pollute ground water.

Research requirements

Water Management (WM) should be part of the total farm management plan. To be successful, irrigation practices and strategies cannot be developed in isolation from the rest of the farm business plan. A few general rules can help make Water Management (WM) more successful (BPA, 1988):

- Know your irrigation system, its capabilities, and its application efficiency. Know your crop water requirements by maintaining good records on water applied; soil moisture conditions, rainfall, and evapotranspiration.
- Do not over-irrigate. Yields may actually be reduced and costs will increase, cutting into profits. Use the services of professional irrigation scheduling companies if time does not permit you to properly schedule your fields.
- Determine which crops must be fully irrigated and which can be partially irrigated if need be.
- Try to irrigate for maximum net income. With those crops that can tolerate partial irrigation, follow these guidelines:
    - Do not underestimate the application efficiency of your system.

  - Irrigate for the ‘average’ point in your field. Do not try to get maximum yields in every corner of the field.
  - Eliminate irrigation that does not pay for itself. This may mean eliminating costly irrigation at the least critical stages of crop growth
- If water becomes limited, irrigate to maximise the profit from each hectare. This means under-irrigating some fields in order to use the water more profitably on other fields.

8.4.3 Farm Structure Optimisation (FSO)

Definition

Farm Structure Optimisation (FSO) is an indispensable final step in obtaining an agronomically, economically and environmentally optimised prototype, by determining (in our case) the amounts of chemical fertiliser and irrigation water application necessary to achieve the required Net Surplus (NS) and Quality Production Index (QPI). Farm Structure Optimisation (FSO) means that the structure of the farm has to be changed or redesigned for better farm production and consequently higher Net Surplus (NS). As will be seen later, in testing with Water Management (WM) (see section 8.6.2), surface irrigation systems in zones A and B must be redesigned to include borders, with suitable land levelling and a water distribution system that ensures efficient water distribution in the field.

Design

- Establishment of a model of a farm structure to quantify the required amounts of chemical fertiliser (if it’s needed) and irrigation water, by fine-tuning the methods of the prototype, Nutrient Management (NM) and Water Management (WM) to achieve the desired Quality Production Index (QPI) and sufficient Net Surplus (NS).
- Establishment of a representative and reliable database on the inputs and outputs of the agronomically and environmentally optimised prototypes.
- Running different scenarios of the Farm Structure Optimisation (FSO) model in interaction with regional stakeholders and pilot farmers.
- In a later stage of the design process, Farm Structure Optimisation (FSO) will be used to disseminate the prototype.

Research requirements

- Quantify losses in quality (prices/kg):
  - dividing achieved price by top quality achievable at the moment of marketing a product (Quality Index);
  - Assigning possible price losses to assessed causes.

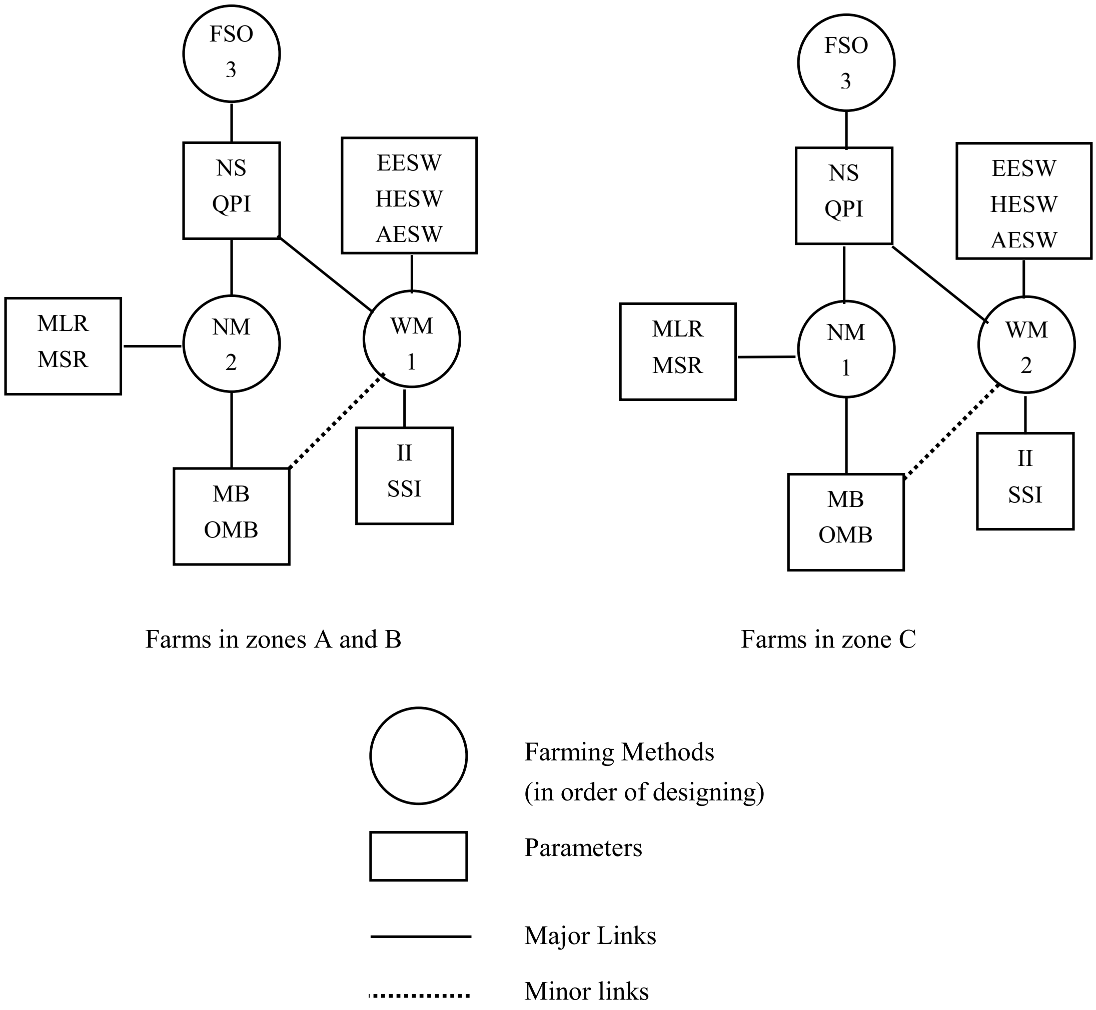
- Quantify losses in production (kg/ha):
  - estimating losses before, during and after harvest;
  - calculating field produced kg/ha = pre-harvest losses + post-harvest losses + marketed kg/ha;
  - dividing marketed kg/ha by field produced kg/ha (Production Index);
  - assigning possible production losses to assessed or probable causes.
- Quantifying and interpreting QPIs:
  - calculating crop-wise QPI = Quality Index X Production Index
  - deciding on improvements to methods if there are shortfalls between desired and achieved QPIs based on assessed possible causes of under performance of crops.

This method will be fully operational after the optimisation of agronomic and environmental aspects of the prototypes to be established in farms. The Net Surplus (NS) parameter serves as indicator for the success of the method.

8.5 Theoretical design of a treated sewagewater using farm in Jordan (prototype)

After quantification of objectives into parameters and identification of farming methods to fulfil these parameters, the next step will be to design a theoretical prototype that links the farming methods with parameters. This design should be multi-objective, and achieve the set of objectives quantified by the set of parameters within a consistent farming system and by mutual support (Vereijken, 1995). The researcher helps the farmers to visualise the results of table 8.7 in order to give them an overview on how to organise the new farming system in their farms. This will make it easier for the farmers to learn how to connect the selected farming methods with the quantified parameters. Figure 8.5 presents the way in which the methods are linked to one another, including the order in which they should be better designed for zones A, B and C.

Such a theoretical prototype gives an idea about where the farmers have to begin. For farmers in zones A and B, figure 8.5 (left side) clearly shows that starting with Water Management (WM) will benefit their conversion right from the beginning. While farmers in zone C, on the right side of figure 8.5, think that Nutrient Management (NM) will do this. The following year, farmers in zones A, B and C will continue with the other farming methods. Farm Structure Optimisation (FSO) is a general finalising method that will provide tools to determine the need to scale up the operation in order to render it environmentally and economically viable. So, year after year all of them will know what they must do, which in turn motivates them to learn to think in terms of larger scales and longer term periods.



Farms in zones A and B

Farms in zone C

Figure 8.5 Visualisation of a prototype of an integrated farming system (after Vereijken, 1995). The one on the left is for zones A and B and the one on the right for zone C. The numbers inside the circles indicate which farming method should be addressed at which moment. The links between circles and squares indicate which farming method best serves a parameter.

What farmers need to do after the creation of theoretical prototypes is to check whether the design is capable of success in the conversion process. They need a method and a tool to give them insight into the success of their management and inform them how far they are from their quantified parameters. Laying out the prototypes in farms, where farmers and researchers work together during the growing season, is a way to do that.

In conclusion, the theoretical prototype should secure the inter-linkage of the new methods at all crop production levels: physical, biological-agronomic, product-market, and farm level. Otherwise objectives will not be achieved and the sustainability and productivity of the crop will be damaged.

Conventional methods only serve one or two of the objectives, and mainly harm the others. The new methods avoid this. Nutrient Management (NM) and Water Management (WM) methods are important for the prototype as freshwater resources decline and costs for fertilisation and irrigation rise. Besides, inefficient irrigation practices and planning may contribute to aquifer depletion and the movement of nitrate and phosphorus into surface and ground water. This effect is related to the fact that most conventional, densely grown, irrigated crops receive irrationally high levels of fertilisers, especially nitrogen and large amounts of irrigation water.

8.6 Testing the prototypes in practice

Before testing the prototypes in the pilot farms, two studies were carried out in 1999-2000 in these pilot farms with the co-operation of two Dutch researchers from Wageningen University to test how nutrients and irrigation water are managed under conventional farming systems in Jordan (see sections 7.3 and 7.4).

Conventional farming systems in Jordan are characterised by high-yielding crops needing a lot of water, fertilisers and equipment to maintain soil fertility. A summary of the results of these studies is presented in Appendixes 8.3, 8.4, 8.5, and 8.6.

In the year 2000-2001 an initial version of the prototypes was laid out and tested at the same pilot farms and on the same fields. By testing it will become apparent to what extent the desired results for any parameter have been achieved. If a shortfall appears between achieved and desired results, the prototypes should be improve with regard to the specific parameter in question, by adjusting the major or minor methods involved according to the theoretical prototypes. Because it is a most laborious and expensive step, requiring at least a full rotation of the prototype on each field (4-6 years), testing and improving the prototype is done in close collaboration with the pilot farmers. They continue to layout the prototype themselves each year at their farms until the achieved results match the desired ones.

The data related to parameters and methods are recorded in Microsoft Excel and Word computer programmes. In accordance with the methods’ research plans a number of tables are constructed with data provided by growers, and measured by the growers and the researcher (Appendix 8.7). The researcher used the data of the filled tables to calculate the parameters achieved for every crop each year. Results were also shown to the farmers in practical form using figures and tables.

8.6.1 Lay out in practice

Maps 8.1 to 8.6 show layouts of the prototype on pilot farms located in different zones, one in zone A, two in zone B and three in zone C respectively. These farms (Table 8.8) differ in two or more of the following factors: water quality (treated sewagewater), microclimate (Siel Al Zarqa and Jordan valley), soil type (clay, silt, sand or mixture of these) and plantation type (fodder, vegetables or trees).

Table 8.8 Selected farms and crops

Zone	**Farm**	**Area (dunum)** [a]	**Crops grown**	**Distance from (Km)**		**Irrigation method**	**Source of water**	**Site number** [d]
				As Samara WWTP [b]	KTD [c]			
A	A1	6.1	Alfalfa	7	--	Surface (Border)	Stream (treated sewagewater), free of charge	Between Site 4 and Site 5
B	B1	30.5	Alfalfa	15	--	Surface (Basin)	Stream (mixed water), free of charge	Site 5.1
	B2	14.4	Apricot	20	--	Drip	Stream (mixed water), free of charge	Site 7
C	C1	1.1 1.4	Tomato, Cucumber	70	25	Drip Drip	KTD (mixed water), farmers pay for it	Site 600
	C2	3.8 2.2	Onion, Cucumber	60	15	Drip Drip	KTD (mixed water), farmers pay for it	Site 600
	C3	4.5 8.7	Tomato, potato	70	25	Drip Drip	KTD (mixed water), farmers pay for it	Site 600

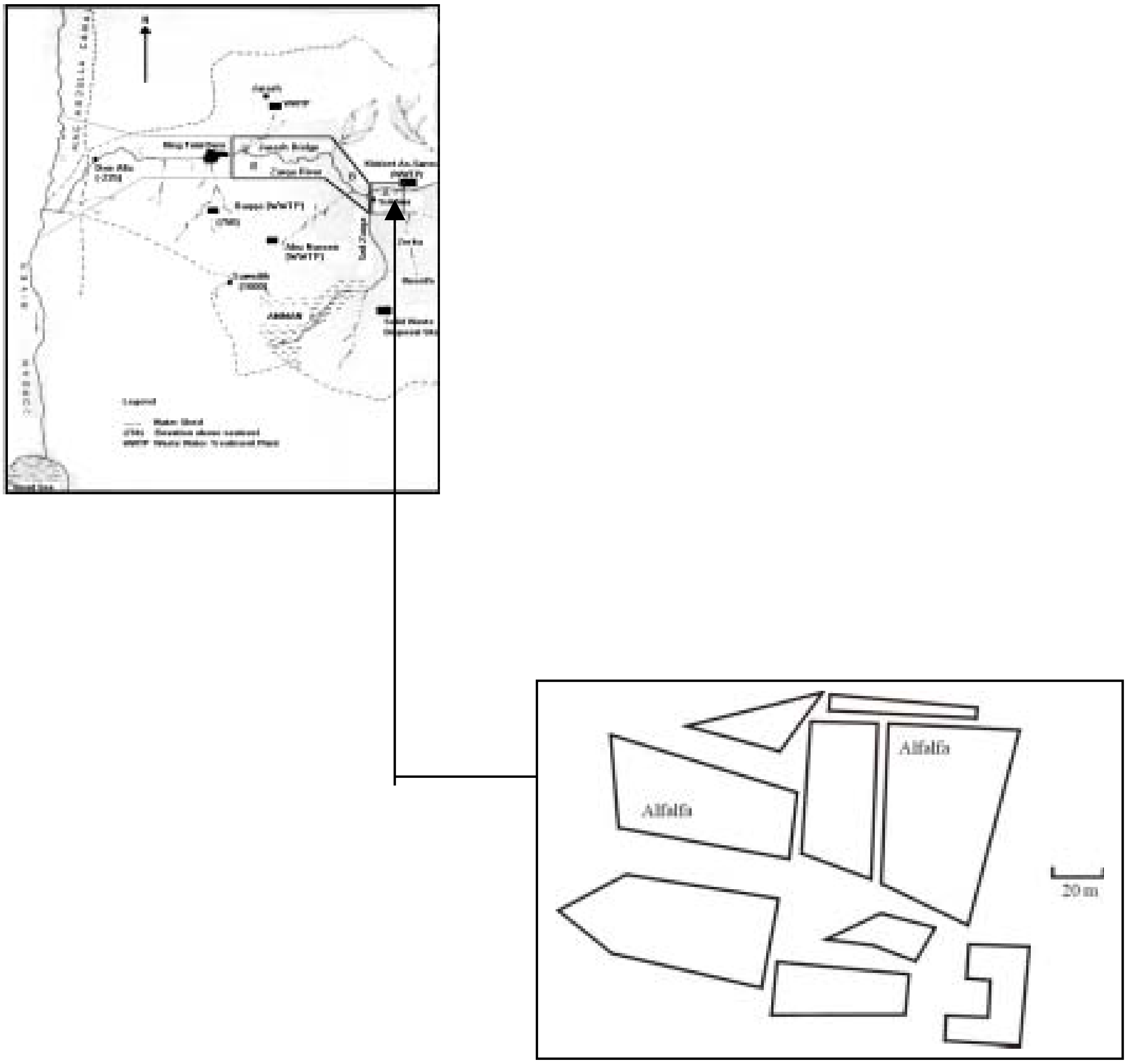
[a] 1 dunum = 1000m^2

[b] Waste Water Treatment Plant

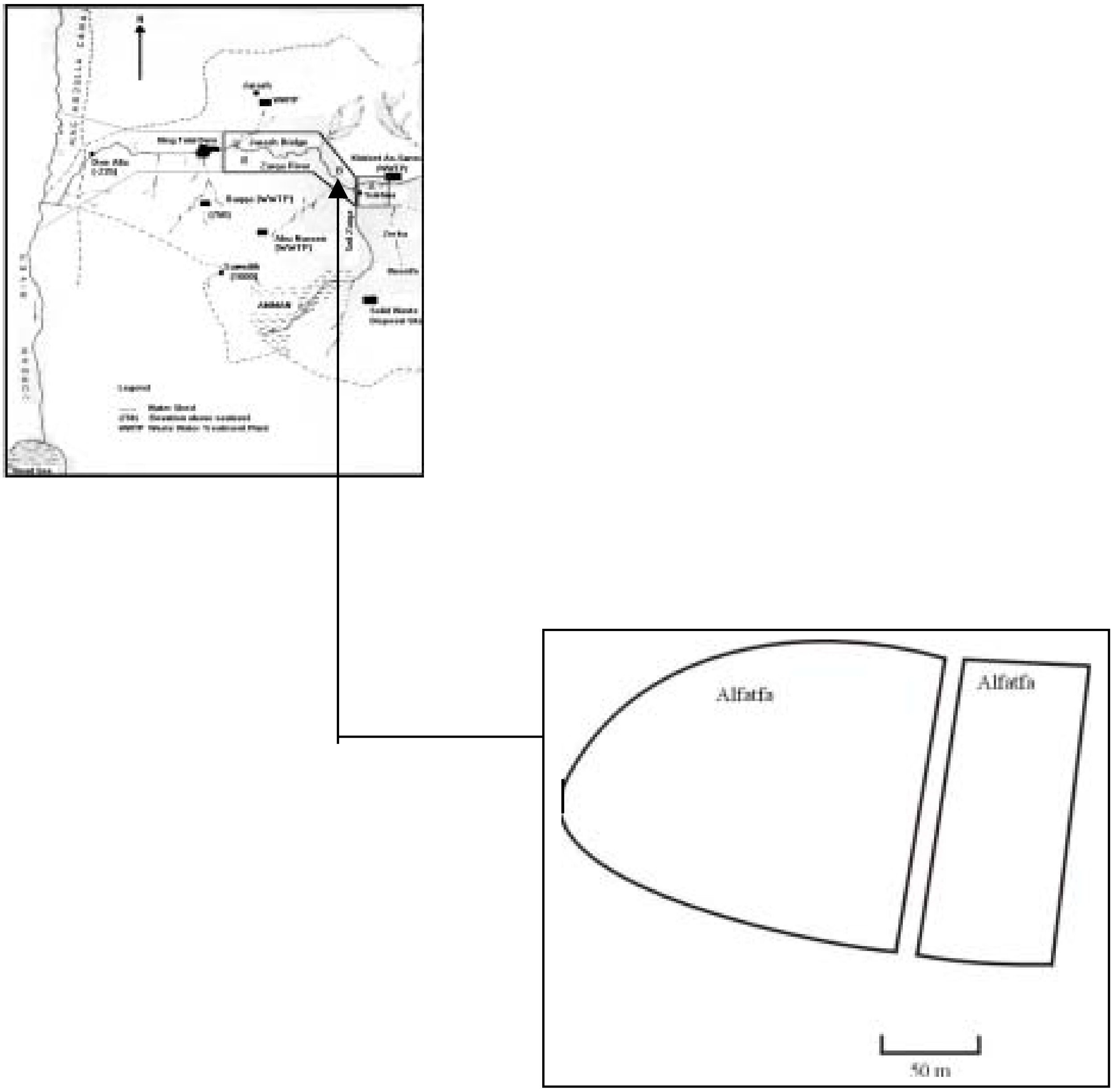
[c] King Talal Dam

[d] see map 7.1 and table 7.1 and 7.12 for location and water quality. No pilot farms at site 100 because it represent the inlet of KTD

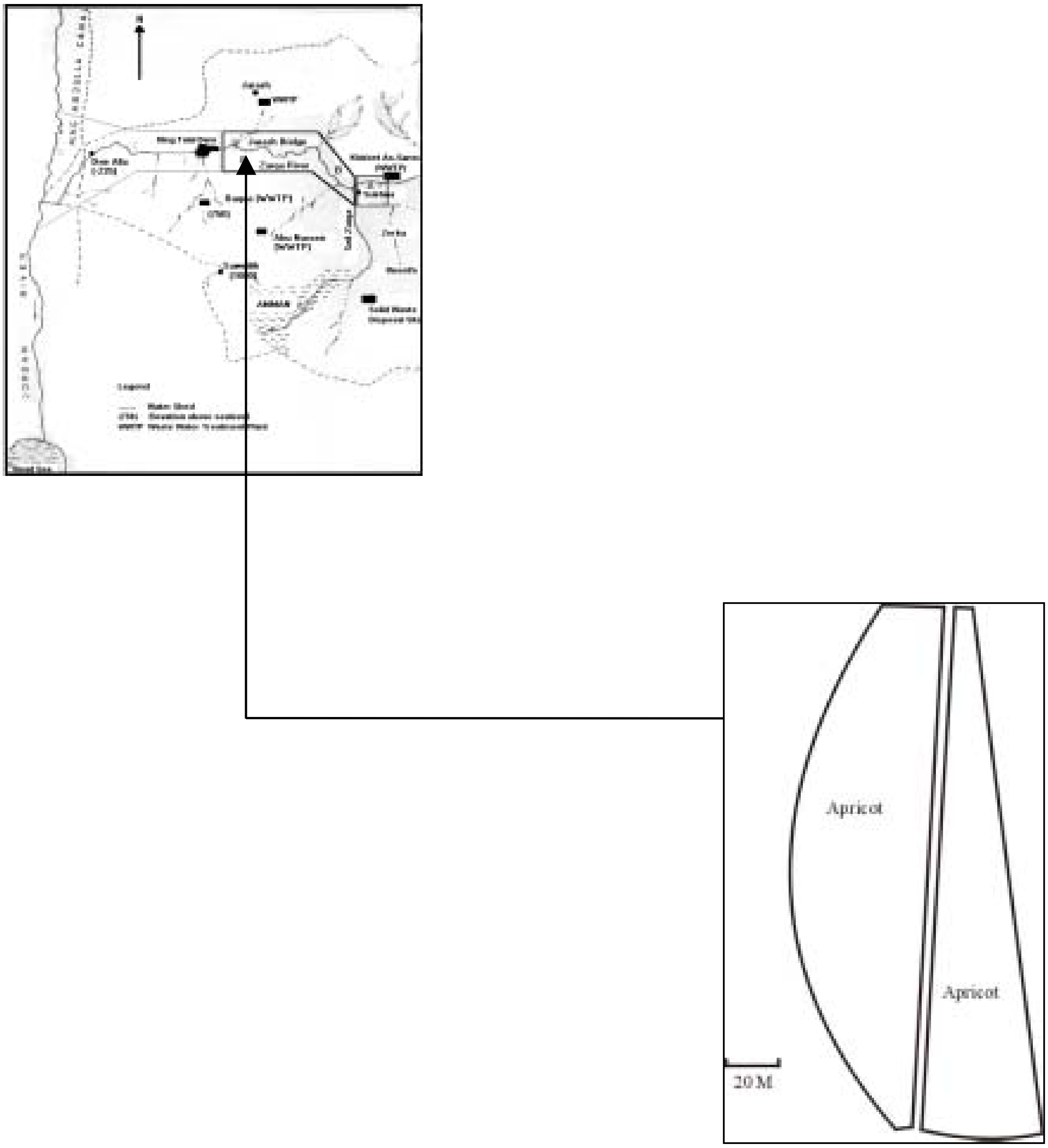
The results are presented in order of the three major farming methods required to achieve the objectives, as transformed and quantified in the set of 11 multi-objective parameters (see theoretical prototype in Figure 8.5 and section 8.4).



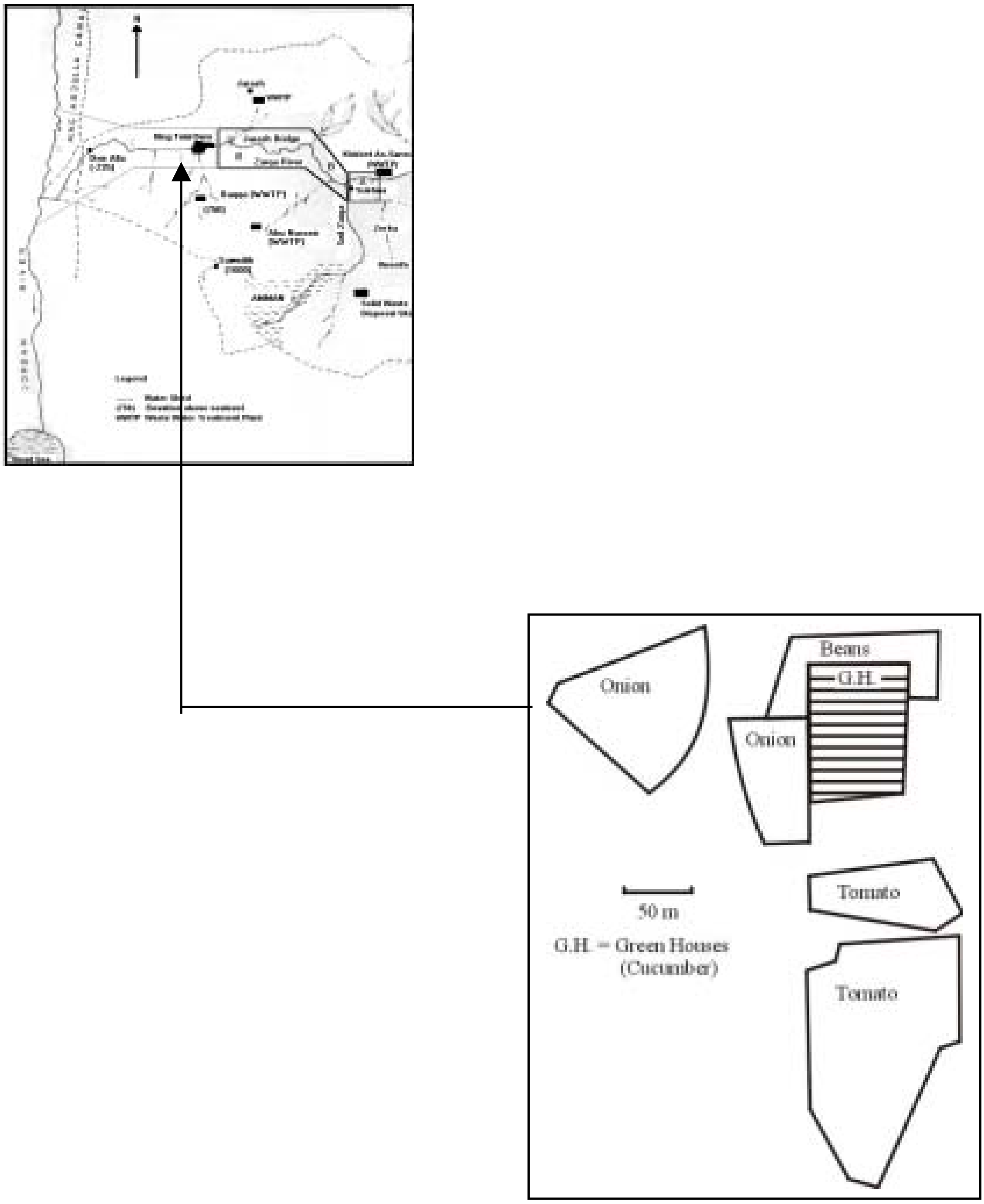
Map 8.1 Layout of treated sewagewater use in irrigation prototype in farm A. The farm water quality, which is within site 4, is represented in table 7.1



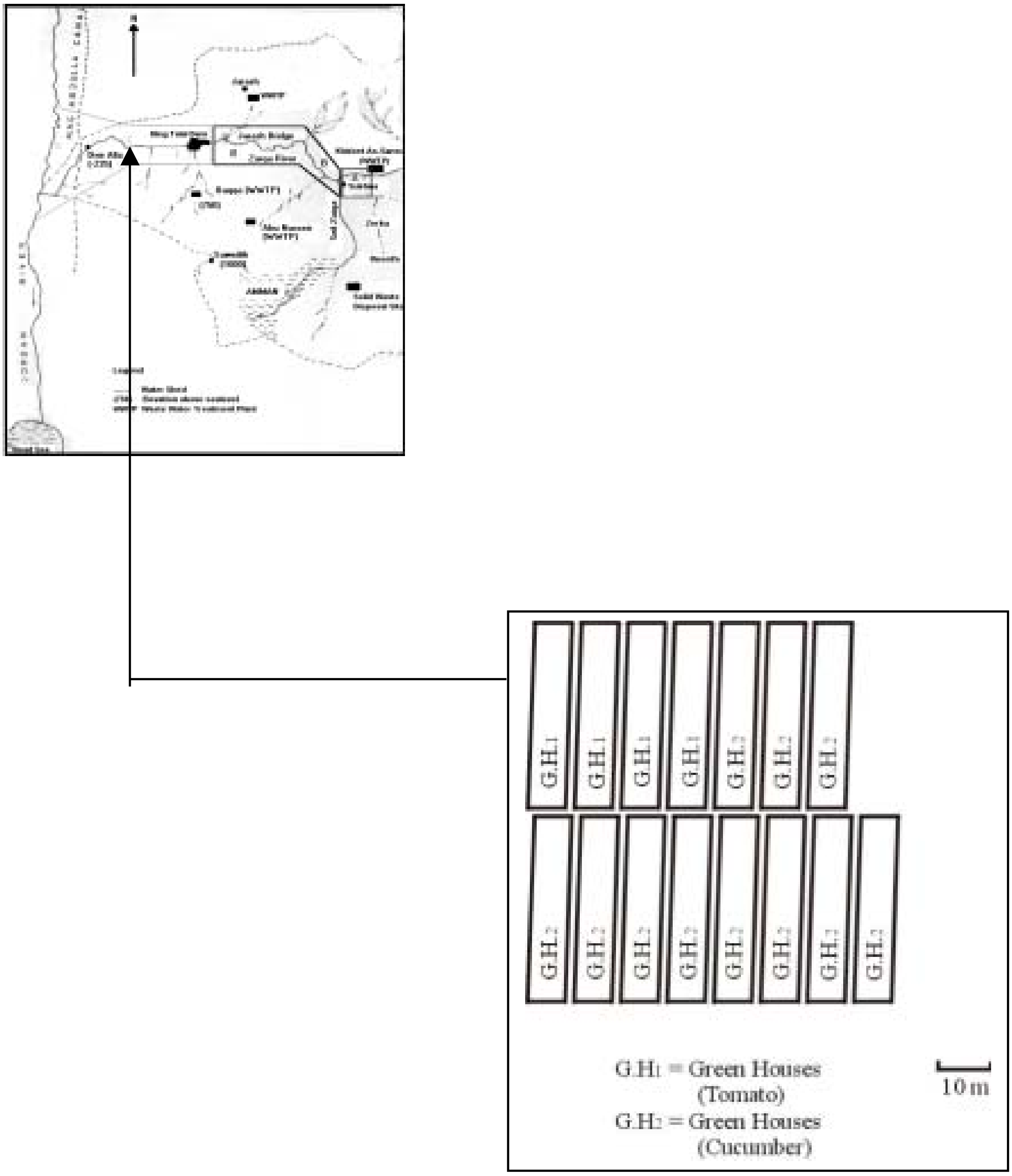
Map 8.2 Layout of treated sewagewater use in irrigation prototype in farm B1. The farm water quality, which is within site 5, is represented in table 7.1



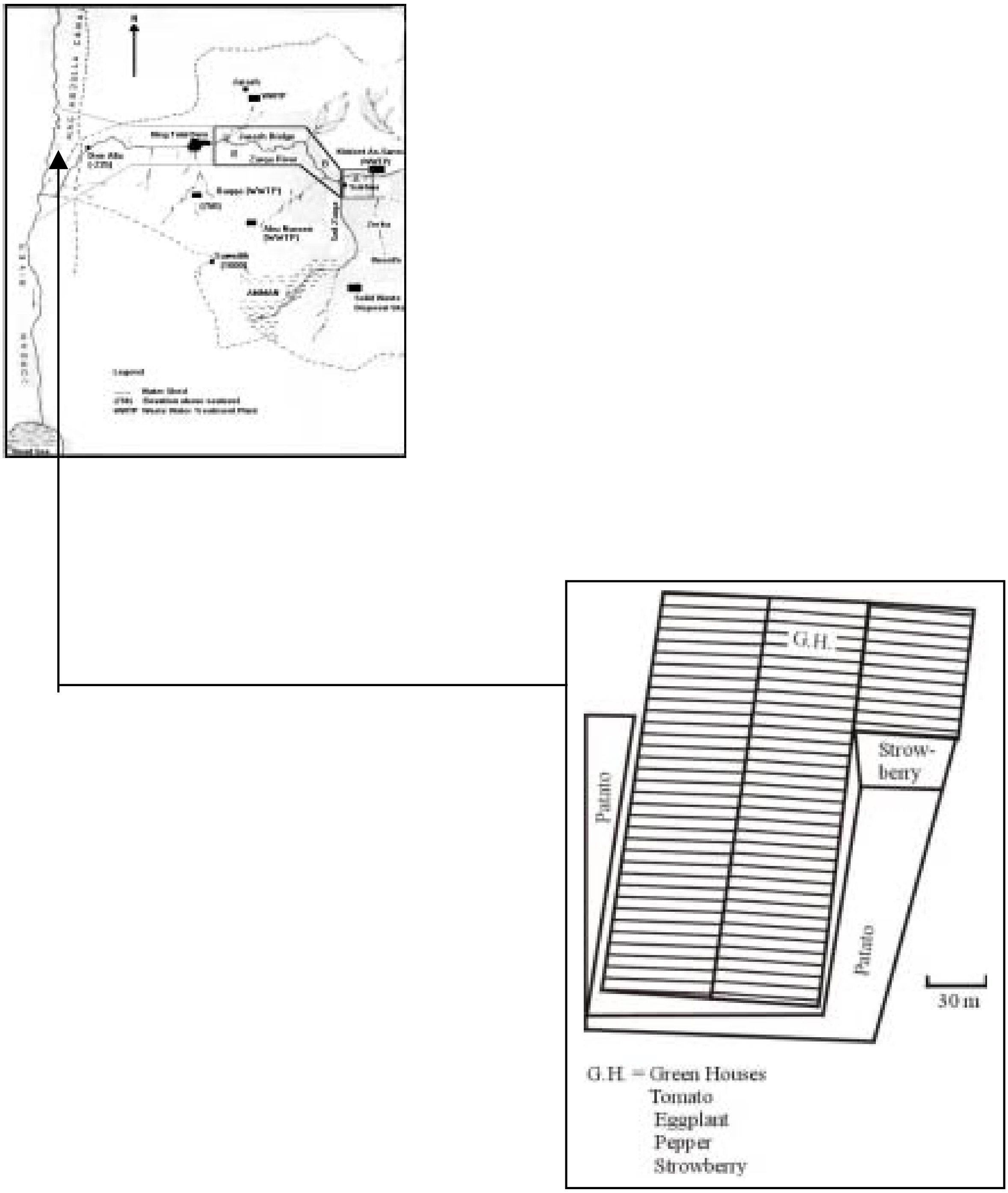
Map 8.3 Layout of treated sewagewater use in irrigation prototype in farm B2. The farm water quality, which is within site 5.1, is represented in table 7.1



Map 8.4 Layout of treated sewagewater use in irrigation prototype in farm C1. The farm water quality, which is within site 100, is represented in table 7.1



Map 8.5 Layout of treated sewagewater use in irrigation prototype in farm C2. The farm water quality, which is within site 600, is represented in table 7.1



Map 8.6 Layout of treated sewagewater use in irrigation prototype in farm C3. The farm water quality, which is within site 600, is represented in table 7.1

8.6.2 Testing the nutrient management method

Nutrient Management (NM) is the major method to achieve desired results in Nitrogen, Phosphorus and Potassium Soil Reserves (NSR, PSR, and KSR), Nitrogen, Phosphorus and Potassium Leaf Reserves (NLR, PLR, and KLR), Macro-nutrient Balance (MB) and Organic Matter Balance (OMB).

Figure 8.6 presents the NSR, PSR, and KSR throughout the pilot farms. Soils are rich in potassium and phosphorus as levels in all soils are above the marginal range. The nitrogen levels are more varied and range from above to within the marginal range. A decline in the nutrient content over the sampling depth is visible for all the fields. The rooting depth of the crop determines the part of the nutrient excess in the soil that is in principle still available to plants. The result of soil analysis indicates leaching of nutrients through the application of water because of the amount of P and K found in 30-60 cm layers are still high. Mineral N is more mobile in the soil and easily leaches to deeper soil layers. The fact that the highest concentrations of nutrients are found in the top layers of soil of the selected fields reflects the unbalanced nutrient management that has been supplied through fertilisers and manure in zone C, and over-irrigation in zones A and B before the application of the prototype, where irrational and inappropriate use of chemical fertilisers and irrigation water are practised.

Comparing soil nutrient reserves, before and after the prototypes are laid out in pilot farms, shows that the Nutrient Management (NM) method gives a better condition in soil nutrient reserves than the conventional farming system, but not within the desired range. Farmers are used to the conventional farming system, where chemical fertilisers and irrigation water are applied in an irrational way without considering the exact needs of the plant. Farmers often think that more fertilisers and water automatically lead to a higher crop production and consequently more money. A one-year application of the Nutrient Management (NM) method is not enough to change this mentality. Farmers need time, motivation and encouragement to manage nutrients effectively. Initial results of testing with soil reserves therefore indicate that the Nutrient Management (NM) method is not yet fully manageable by the pilot farmers. Appendix 8.3 presents the NSR, PSR, and KSR during the conventional management phase in pilot farms.

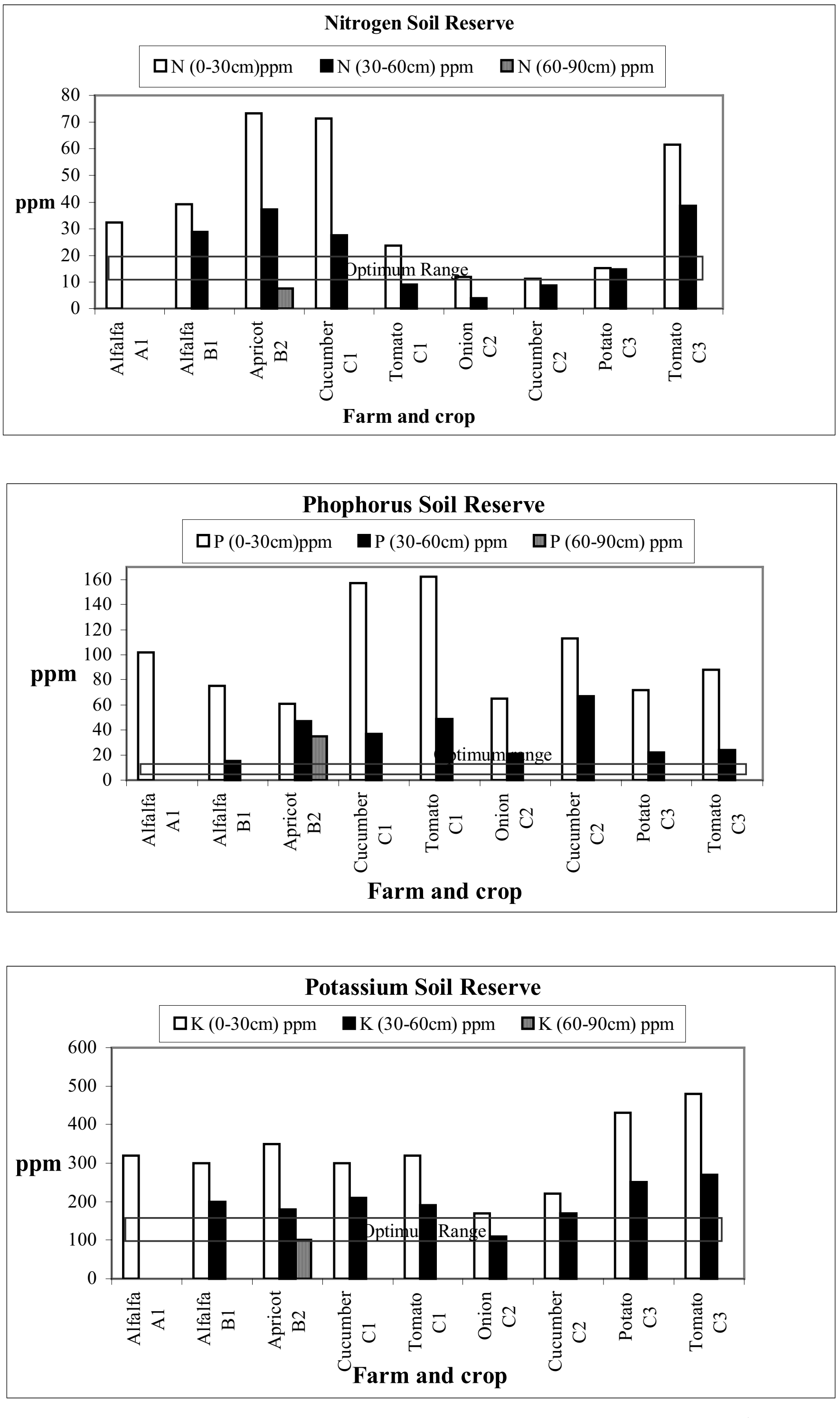
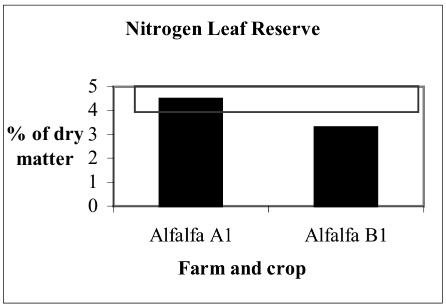
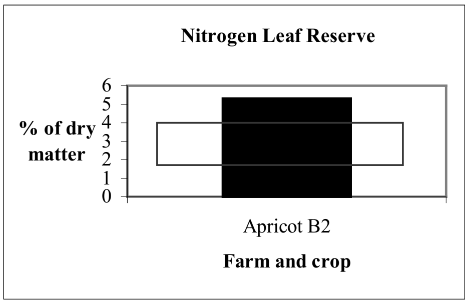
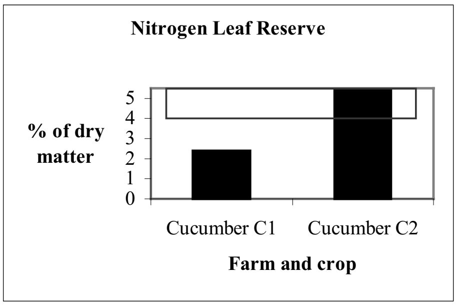
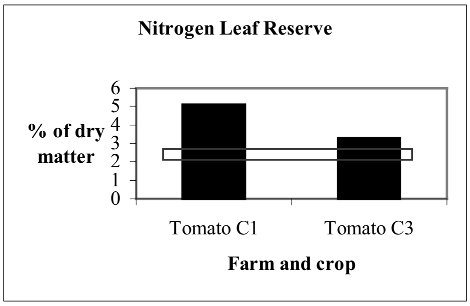


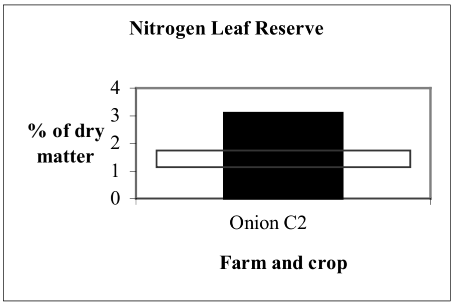
Figure 8.6 Mineral Nitrogen ($N\text{-}NO_3$ plus $N\text{-}NH_4$), Extractable Phosphorus (P) and Extractable Potassium (K) Soil Reserves at pilot farms in zone A, B and C at 2000-2001 growing season. Vertical columns indicates $N\text{-}NO_3$ plus $N\text{-}NH_4$, P and K values in soil at depth indicated in the legend in part per million (ppm) (1 ppm = 1 mg/kg). Horizontal columns indicate the desired ranges of N, P and K in soil in ppm. These values adapted from Garabet et al., 1996 (see Appendix 8.2).











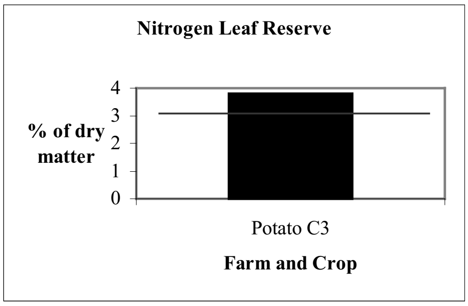


Figure 8.7 Total Nitrogen (N), Phosphorus (P) and Potassium (K) Leaf Reserves at pilot farms in zone A, B and C at 2000-2001 growing season. Vertical columns indicates the NLR, PLR and KLR values in parts per million (ppm) (1 ppm – 1 mg/kg). Horizontal columns indicates the desired rangers of NLR, PLR and KLR adapted from various resources (see Appendix 8.1)

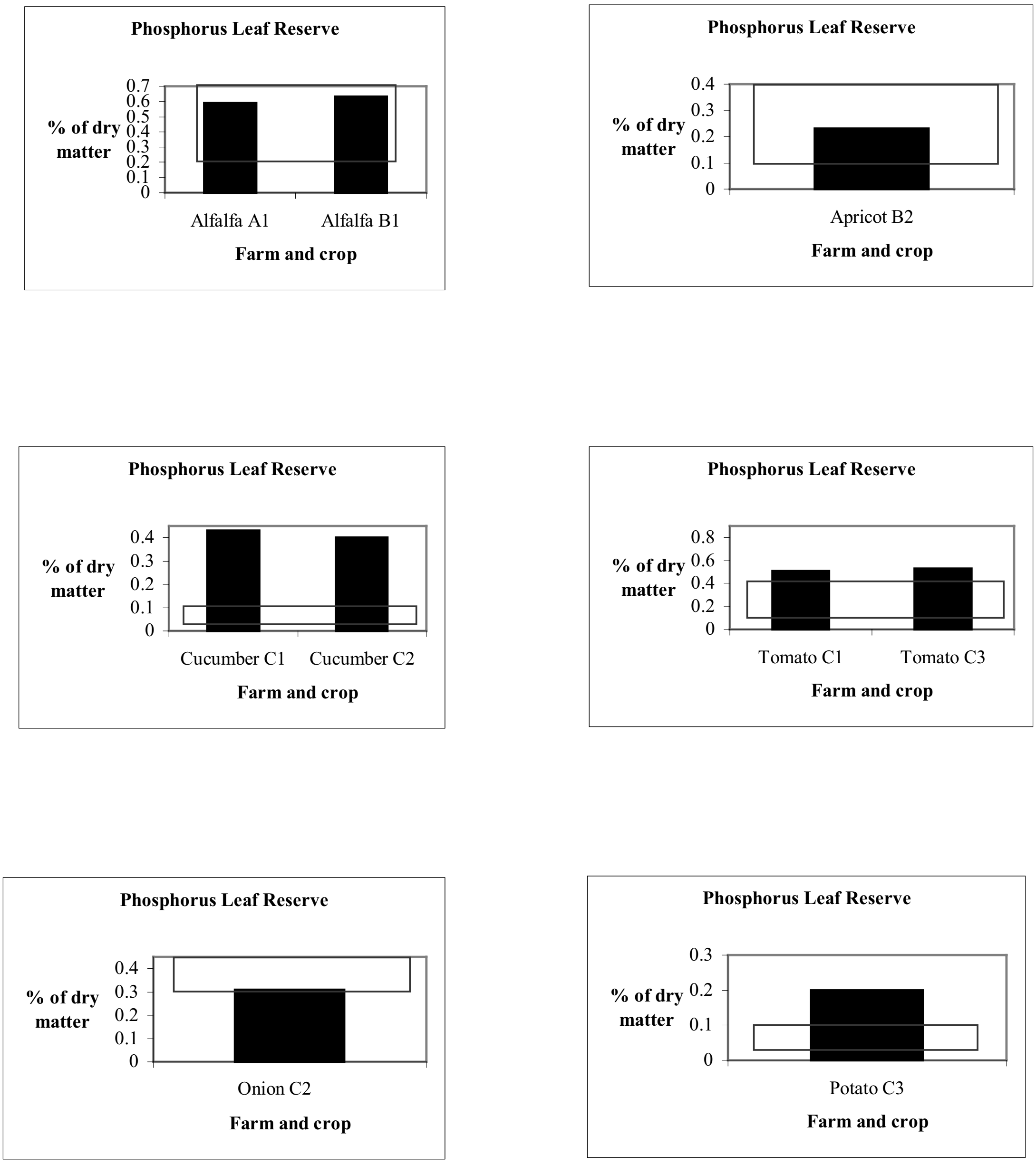
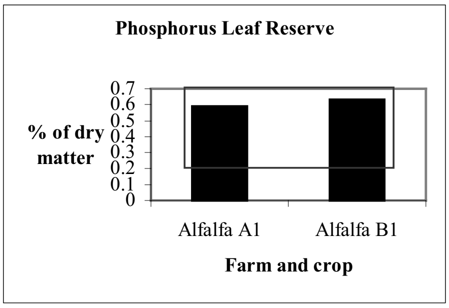
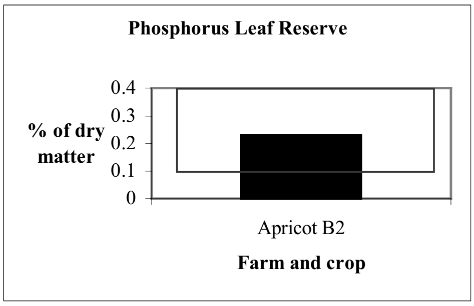
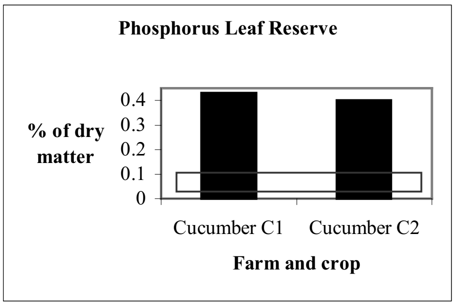
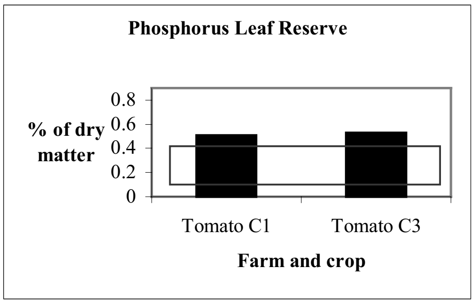


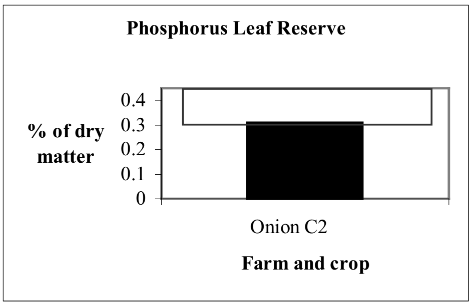
Figure 8.7 Continue











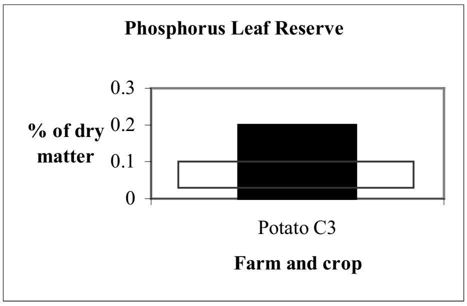


Figure 8.7 Continue

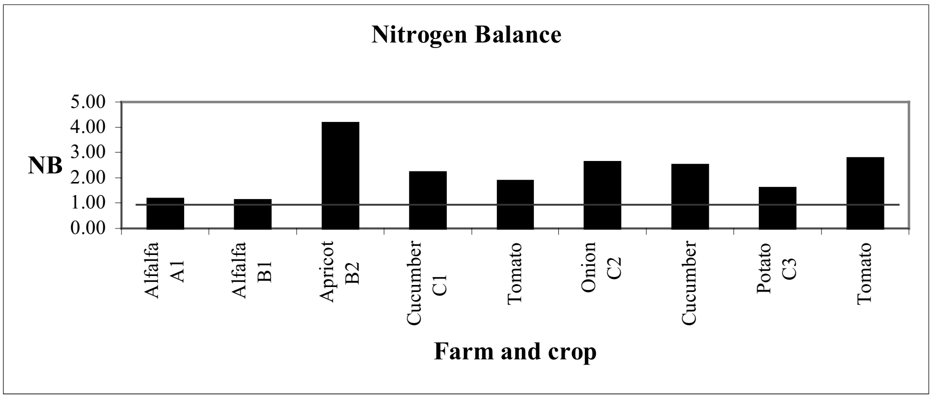
Figure 8.7 presents the NLR, PLR, and KLR throughout the pilot farms. Again NLR, PLR and KLR results show better leaf reserve conditions in the 2000-2001 growing season (after laying out the prototypes) than the 1999-2000 growing season (before laying out the prototypes, see Appendix 8.4).

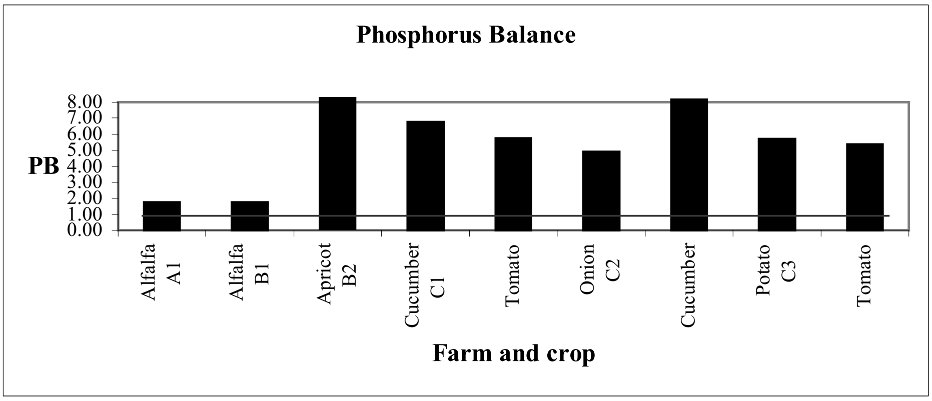
All farms in zones A and B show results within the optimum range, which indicates that NLR, PLR and KLR were managed effectively in almost all of the pilot farms. This is because the farms rely only on the nutrients that are present in the treated sewagewater for crop production, except for farm B_2 where supplemental fertilisation was needed. While in zone C, the results show that NLR, PLR and KLR fluctuated above, below or within optimum range. This was due to the imbalance in nutrient management prior to application of the prototypes. More than the optimum range for all the nutrients found in crops points to over-consumption and can reduce the growth of yield (Reuter, 1997), while low or deficient levels points to weak uptake by crops. These results are related to previous nutrient management, which was based on the irrational and inappropriate use of chemical fertilisers. Initial results of testing with Leaf Reserves show that the NM method is not yet fully managed by pilot farmers in zone C.

Figure 8.8 presents Macro-nutrient Balances (MB). However, most farms have NB, PB, and KB>1. The more NB, PB and KB exceeds 1, the greater the risk of exceeding the desired range. At present we do not know to what extent NB, PB and KB may be permitted to exceed 1, to compensate for N volatilisation, P fixation on calcareous soil and net K mineralisation from clay soils. We have therefore been cautious when quantifying the desired range in NB, PB and KB, by assessing a provisional norm = 1. These initial results of testing with macro-nutrient balances show that the Nutrient Management (NM) method is not yet fully manageable by the pilot farmers. Appendix 8.5 presents the MB during the conventional management phase of the pilot farms.

8.6.3. Testing the water management method

Water Management (WM) is the prime method for achieving desired results in the Irrigation Index (II) and Soil Salinity (EC_e). The Water Management (WM) of the pilot farms have been designed and initially laid out following the demands made by the Water Management (WM) method, as specified in section 8.4.2.





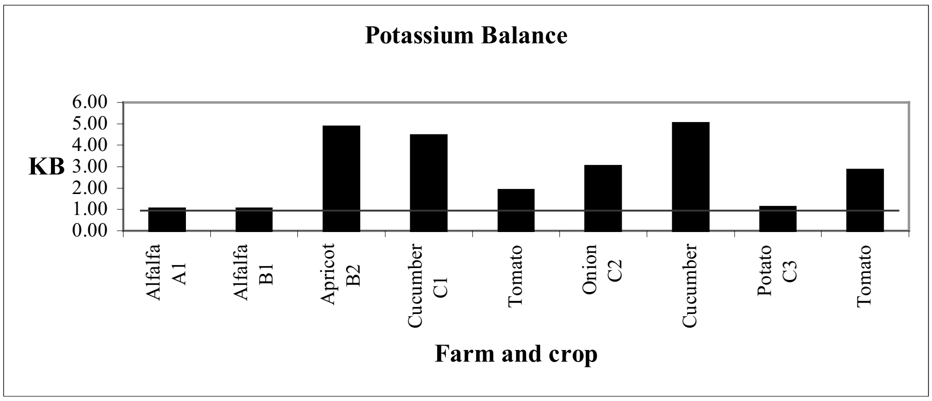


Figure 8.8 Macro-nutrient Balances in pilot farms in zone A, B en C in 2000-2001 growing season. Vertical columns indicate the Nitrogen (N), Phosphorus (P) and Potassium (K) balance. Horizontal lines indicates the desired ranges at this stage of the research.

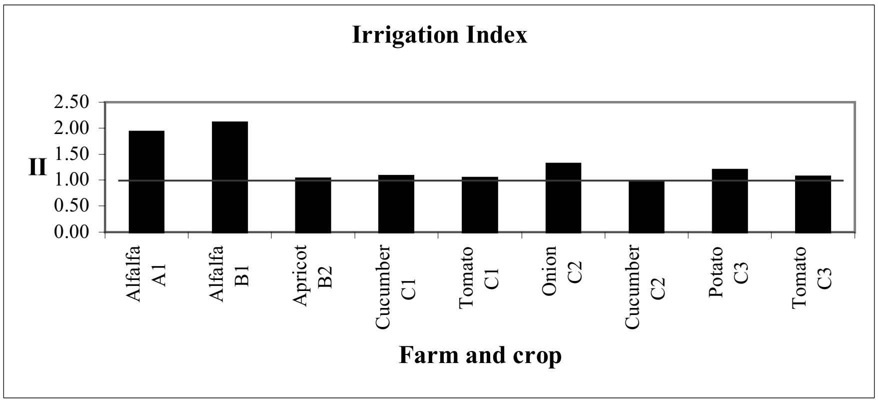
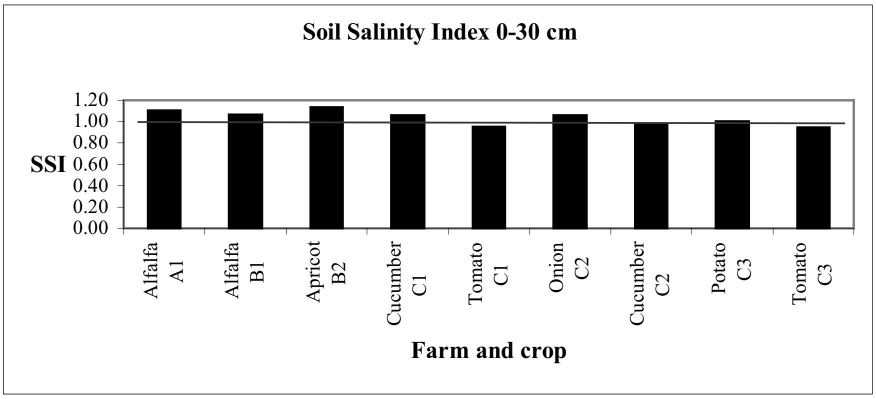


Figure 8.9 Irrigation Index (II) at pilot farms in zones A, B and C in the 2000-2001 growing season. Vertical columns indicate the ratio between water used to water needed. Horizontal line indicates the desired range. These results accure from prototype management, not water quality.



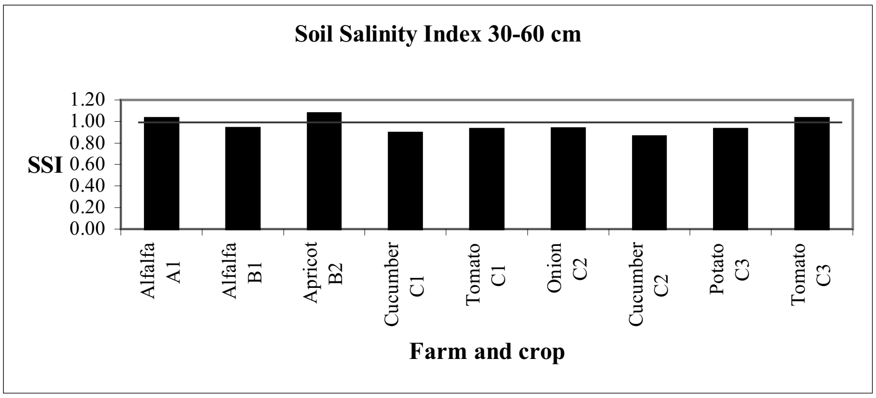


Figure 8.10 Soil Salinity Index (SSI) at pilot farms in zones A, B and C in the 2000-2001 growing season. Vertical columns indicate soil salinity (Ece) ratio at the beginning of the growing season and at harvest. Horizontal line indicates the desired range. These results accrue from prototype management, not water quality.

Figure 8.9 presents the II throughout the pilot farms. Most of the farms are within the desired result. Farms A1 and B1 use surface irrigation methods and acquire water immediately from the stream free of charge. Consequently, the farmers tend to over-irrigate and do not time irrigation in a rational or a scientifically sound way. These farmers are contributing to over-exploitation of water resources in the area. The other farms use a drip irrigation method and all of them except farm B2 receive water through pipe systems from the Jordan Valley Authority (JVA) for which they pay. The initial results of testing with the II show that the Water Management (WM) method is managed effectively in the pilot farms. Only farms A1 and B1 exceed the desired results. Appendix 8.6 presents the II during the conventional management of the pilot farms which, when compared with the II after laying out the prototypes, shows that farmers in zones A, B and C succeeded in decreasing water losses incurred by over-irrigation. This gives us an indication that the Water Management (WM) method is well-managed by almost all the farmers, especially in zone C. These results also show us that the drip irrigation system is an efficient system in terms of reducing water losses in the fields.

For surface irrigation systems, land levelling, a suitable width to length ratio of the field, and a good canal structure to convey water from the stream to the field are needed to distribute water in the field in an efficient way. Farms A and B1 have a deficiency in one or more of these conditions. So an extra amount of water is needed to distribute water to the whole field, and this explains why the II in farm A and B1 is higher than the desired range.

Figure 8.10 presents the Soil Salinity Index (SSI) at depth 0-30cm and 30-60cm. The figure shows that EC_e at the beginning of the growing season and at the end of the growing season has, to an extent, values ranging around the desired result. This suggests that the build-up of salinity in the soil profile during the growing season is negligible. Initial results of testing the SSI show that the Water Management (WM) method is managed effectively in the pilot farms.

Each year before the growing season, the farmers leach the soil by ponding water in the fields to decrease the soil salinity (EC_e) to levels suitable for plant growth. The amount of water needed to leach the soil depends on the soil and water salinity. High salinity means large quantities of water are needed to leach the soil. By stopping the degradation in soil salinity, as the SSI shows for the 2000-2001 growing season, the quantity of water needed to leach the soil will be less, and this has a positive impact in the long run.

More details about irrigation and salinity indexes are presented in Appendix 8.7 part D.

8.6.4. Testing the farm structure optimisation method

Farm Structure Optimisation (FSO) is the method to achieve the desired result in Net Surplus (NS), if all the other methods do not succeed in doing so, and contributes to achieving desired results in QPI.

Figure 8.11 presents the Quality Production Index (QPI) throughout the pilot farms. Pilot farms have similar QPIs, as farmers usually bring their commodities to the market collectively. All crops are below the desired result, and this is due to losses in yield through harvesting and failure to achieve top quality price. Losses through harvesting means that farmers sometimes will not harvest the crop at suitable time, which cause a product quality not preferred by the market (consumers). This will force the farmers to sell this product at prices lower than the market price or sometimes to destroy it. The other cause for the low QPI is the low Quality Index (QI) due to low market prices. Many outside markets, especially in the Gulf area, rejected the Jordanian products on account of its low quality (as they said), thereby causing too much of the commodity entering the local market at low prices. This explains the fact that losses in QPI are not confined to our pilot farms, but it is a general condition to all Jordanian farms.

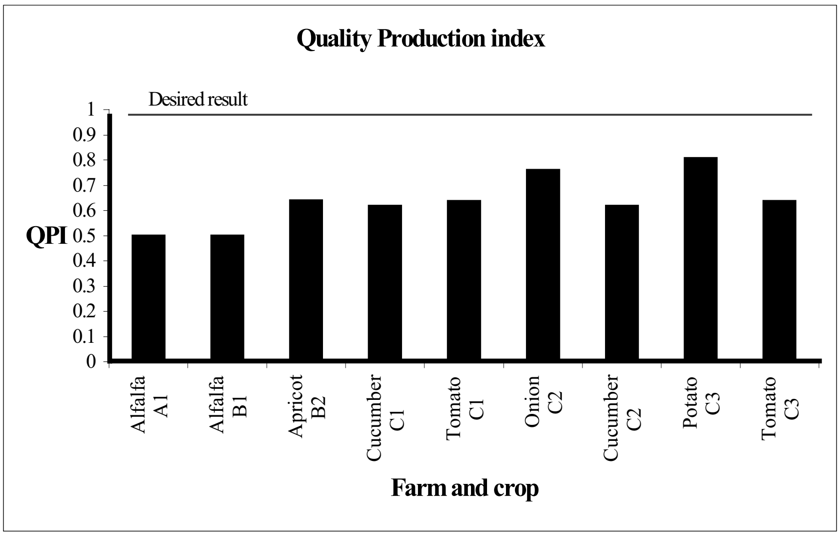


Figure 8.11 Quality Production Index (QPI) at pilot farms in zones A, B and C for the 2000-2001 growing season. Vertical columns indicate the QPI in all farms. Horizontal line indicates the desired range. These results accrue from prototype management, not water quality

The initial results of testing with the QPI show that the Nutrient Management (NM) and Water Management (WM) methods were not yet fully effective in changing the perspectives of consumers or importing countries.

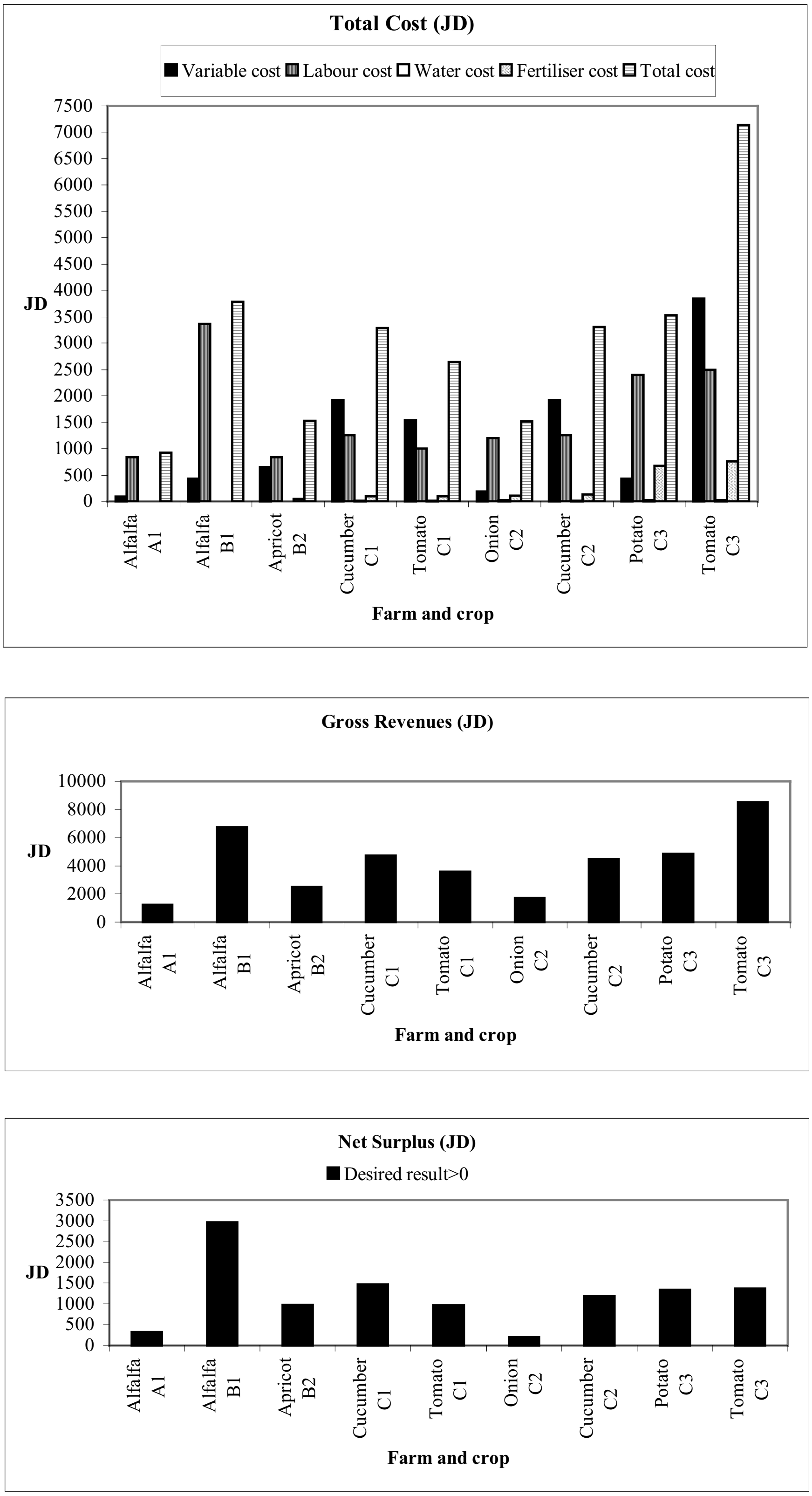


Figure 8.12 Net Surplus (NS) at pilot farms in zones A, B and C for the 2000-2001 growing season. These results accrue from prototype management, not water quality

Figure 8.12 presents Net Surplus (NS) throughout the pilot farms. All crops succeeded in obtaining a desired NS. As mentioned earlier (see section 8.3), at this stage of the research the NS will test only the effectiveness of the Nutrient Management (NM) method and Water Management (WM) method in decreasing the amount of chemical fertilisers and irrigation water without any loss in the quality and quantity of production. Table 8.9 presents the costs of chemical fertiliser and water for all pilot farms in the study area both before and after laying out the prototypes.

Table 8.9 Cost of water and chemical fertilisers applied to the farms in zones A, B and C during the 1999-2000 and 2000-2001 growing seasons.

Farm	**Crop**	**Cost 2000 (JD)**			**Cost 2001 (JD)**		
		Water	Fertiliser	Total cost	Water	Fertiliser	Total cost
A1	Alfalfa	0.0	0.0	0.0	0.0	0.0	0.0
B1	Alfalfa	0.0	0.0	0.0	0.0	0.0	0.0
B2	Apricot	0.0	41.0	41.0	0.0	41.0	41.0
C1	Cucumber	9.0	156.0	165.0	6.0	103.0	109.0
	Tomato	9.0	144.0	153.0	6.0	94.0	100.0
C2	Onion	63.0	138.0	201.0	18.0	115	133.0
	Cucumber	23.0	272.0	295.0	8.0	127.0	135.0
C3	Potato	29.0	1314.0	1343.0	20.0	676.0	696.0
	Tomato	14.0	1606.0	1620.0	25.0	761.0	786.0
Total		147.0	3671.0	3818.0	83.0	1917.0	2133.0

The table shows that a reduction in the costs of chemical fertilisers and water equal to about 1800 Jordanian Dinars (JD) was achieved after laying out the prototypes in the pilot farms (2000 - 2001 growing season). What about the yield? Is there any effect on the quantity of the crop yields? Table 8.10 presents the average yields for Jordan, the yields of all the farms in the study area before and after laying out the prototypes and the yield market prices of all the farms in the study area before and after laying out the prototypes. The table shows a difference between the average yields for Jordan and the yields of all the pilot farms, either before or after laying out the prototype, except for Apricot and Onion. This difference is caused either by the great fluctuation in average yields for Jordan (one growing season with high yield and others with low yields) or because some farmers sell their yields immediately to consumers or other private organisations instead of the local market. The local market is a place where all farmers bring their crops to be sold to small enterprises, and in turn these enterprises will sell these crops to the consumers.

The table also shows a fluctuation in crop yield after the prototypes were laid out in the pilot farms for the first year, either higher or lower than the crop yield figures during conventional farming. This is a true fact especially when new farming system is introduced. It is therefore not easy to generalise after one year of trial (laying out the prototype), as effects could be due to climatic conditions rather than prototype application. As mentioned before, in order to arrive at a general conclusion, a full rotation of the prototype on each field (4-6 years) is needed.

It also shows a fluctuation in crop yields between pilot farms before or after laying out the prototype. Cucumber and Tomato yields at farm C1 is higher than Cucumber yield at farm C2 and Tomato yield at farm C3. The problems facing farmers (e.g. diseases, low water quality, salinity, soil deterioration, etc.) are more abundant in farms C2 and C3 than in farm C1.

Table 8.10 Average yields for Jordan compared with yields of all farms in zones A, B and C during the 1999-2000 and 2000-2001growing seasons and yields market prices of all farms in zones A, B and C during the 1999-2000 and 2000-2001growing seasons.

Farm	**Crop**	**Average yield for Jordan * (Ton/Dunum **)**	**Yield (Ton/Dunum)**		**Price (JD)**		
		2000	2000	2001	JD / Ton ****	Total in 2000	Total in 2001
A1	Alfalfa	Not available	19	24.7	8.3	962.0	1250.6
B1	Alfalfa	Not available	30	26.6	8.3	7594.5	6733.8
B2	Apricot	0.58 ***	0.41	0.39	450	2655.0	2498.0
C1	Cucumber	11.99	36.36	43.18	100	4000.0	4750.0
	Tomato	4.37	28.57	25.7	100	4000.0	3600.0
C2	Onion	3.36	4	3	150	2280.0	1710.0
	Cucumber	11.99	15.9	20.45	100	3500.0	4500.0
C3	Potato	2.64	7.55	7.73	140	4760.0	4872.0
	Tomato	4.37	9.2	9.77	100	8000.0	8500.0

* *Source: Department of statistics, Amman Jordan*

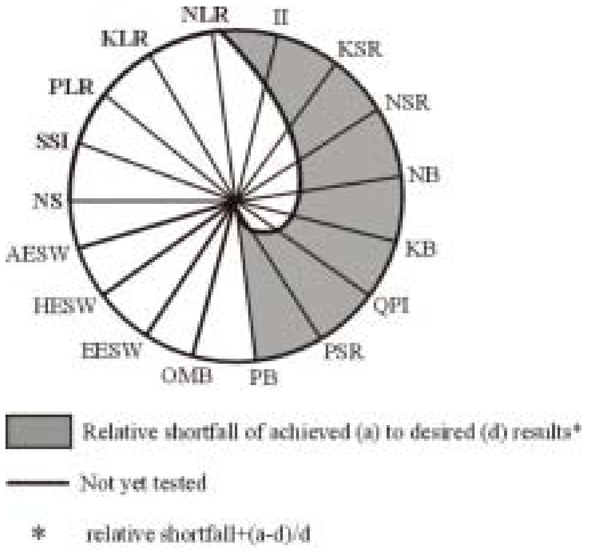
** *Dunum = 1000m²*

*** *Average yield based on each dunum planted with 33 trees, while in our case each dunum planted with 13 trees.*

**** *Average market price*

Table 8.11 Profitability comparison in all farms in zones A, B and C during the 1999-2000 and 2000-2001 growing seasons based on the cost of water and chemical fertilisers added.

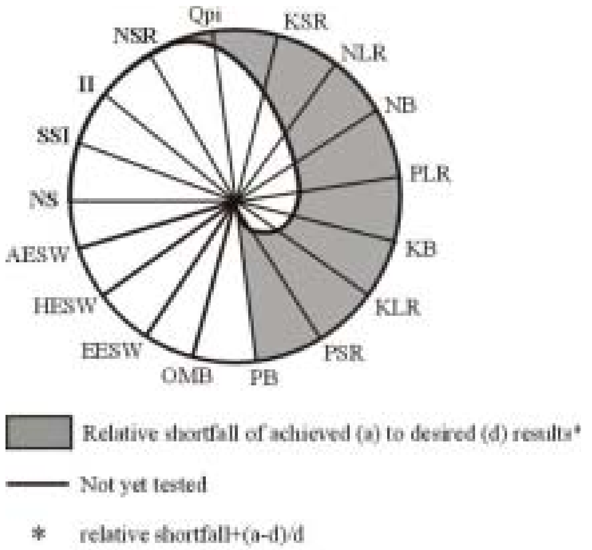
Farm	**Crop**	**Cost in 2000 (JD)**			**Market price**	**Profit**	**Cost in 2001 (JD)**			**Market price**	**Profit**	**Profit difference between 2001 and 2000 (JD)**
		Water	Fertiliser	Total cost	JD / Ton	JD / Ton	Water	Fertiliser	Total cost	JD / Ton	JD / Ton	JD / Ton
A1	Alfalfa	0.0	0.0	0.0	962.0	962.0	0.0	0.0	0.0	1250.6	1250.6	288.6
B1	Alfalfa	0.0	0.0	0.0	7594.5	7594.5	0.0	0.0	0.0	6733.8	6733.8	-860.7
B2	Apricot	0.0	41.0	41.0	2655.0	2614.0	0.0	41.0	41.0	2498.0	2457.0	-157.0
C1	Cucumber	9.0	156.0	165.0	4000.0	3835.0	6.0	103.0	109.0	4750.0	4641.0	806.0
	Tomato	9.0	144.0	153.0	4000.0	3847.0	6.0	94.0	100.0	3600.0	3500.0	-347.0
C2	Onion	63.0	138.0	201.0	2280.0	2079.0	18.0	115	133.0	1710.0	1577.0	-502.0
	Cucumber	23.0	272.0	295.0	3500.0	3205.0	8.0	127.0	135.0	4500.0	4365.0	1160.0
C3	Potato	29.0	1314.0	1343.0	4760.0	3417.0	20.0	676.0	696.0	4872.0	4176.0	759.0
	Tomato	14.0	1606.0	1620.0	8000.0	6380.0	25.0	761.0	786.0	8500.0	7714.0	1334.0
Total		147.0	3671.0	3818.0	37751.5	33933.5	83.0	1917.0	2133.0	38414.4	36281.4	2347.9



Farms in zones A and B

Parameters (indicators for sustainability)	Desired results (quantified objectives)	Achieved results in year 2000-2001	Main causes of shortfall	Methods to be improved according to the criteria: Is it ready for use? (a); Is it acceptable? (b); Is it manageable? (c); Is it effective? (d)
NSR	11-20	40.7	WM	WM (c)
PSR	8-15	73.7	WM	WM (c)
KSR	100-150	256.7	WM	WM (c)
NLR	see Appendix 8.7	see figure 8.7		
PLR	see Appendix 8.7	see figure 8.7		
KLR	see Appendix 8.7	see figure 8.7		
NB	1	2.1	WM	WM (c)
PB	1	8.6	WM	WM (c)
KB	1	2.3	WM	WM (c)
II	1	1.7	WM	WM (c)
SSI	≤ 1	1.0		
NS	> 0	277.7		
QPI	> 0.9	0.6	WM	WM (d)
OMB		Not measured		
EESW		Not measured		
HESW		Not measured		
AESW		Not measured		

Figure 8.13 Evaluation of the results obtained after one year of farming according to the indications obtained by creating a theoretical prototype for farms in Seil Al Zarqa and the Middle Jordan Valley. This evaluation gives a farmer a clear view on what he planned to do in combination with the results that he actually obtained in a certain year. For example, from this evaluation we may conclude that the farmer still has a long way to go, but also that his management of the completed production year was partly successful. He makes himself aware of everything he still has to do through the coming year. The farmer thus learns from the consequences of certain decisions. He learns effectively. This helps him learn from his farm and from his mistakes each year.



Farms in zone C

Parameters (indicators for sustainability)	**Desired results (quantified objectives)**	**Achieved results in year 2000-2001**	**Main causes of shortfall**	**Methods to be improved according to the criteria: Is it ready for use? (a); Is it acceptable? (b); Is it manageable? (c); Is it effective? (d)**
NSR	11-20	22.5		
PSR	8-15	70.0	NM	NM (c)
KSR	100-150	260.0	NM	NM (c)
NLR	see Appendix 8.7	see figure 8.7	NM	NM (c)
PLR	see Appendix 8.7	see figure 8.7	NM	NM (c)
KLR	see Appendix 8.7	see figure 8.7	NM	NM (c)
NB	1	2.7	NM	NM (c)
PB	1	6.1	NM	NM (c)
KB	1	3.1	NM	NM (c)
II	1	1.0		
SSI	≤ 1	0.97		
NS	> 0	500.1		
QPI	> 0.9	0.68	NM and WM	NM and WM (d)
OMB		Not measured		
EESW		Not measured		
HESW		Not measured		
AESW		Not measured		

Figure 8.13 Continued

However, as an initial conclusion, and after laying out the prototype for the first year, it can be pointed out that there was an increase in profit for the year 2001 over the year 2000 in all pilot farms in zones A, B and C equal to 2500 Jordanian Dinars (JD). This was due to the reduction in chemical fertilisers applied and irrigation water application in the study area, as presented in table 8.11.

8.7 Managerial evaluation method for yearly improvement of the redesigned farm

Evaluation of the prototypes can be done by the presentation of the prototype as a circular graph (Vereijken, 1998). Each diameter of the circle represents one of the targets that the farmer had identified earlier in the process of conversion. The more his result approaches the circumference of the circle the greater his success in achieving his managerial objectives. By making this graph year after year the farmer gains insights into his successes and failures.

From figure 8.13 we can conclude that the farmers still have a long way to go, but also that their management of the production year 2000-2001 was partly successful. Farmers make themselves cognisant of everything they still have to do during the next year by learning from the consequences of certain decisions. This helps them learn from their farms and from their mistakes successively each year. This is an example of heuristic learning: learning from one's own successes and mistakes.

Not all farmers in each zone had the same results when they applied the prototype in their fields, even when these were operated using identical methods. By holding a meeting with farmers in each zone and discussing these variations in results, a suitable atmosphere is created in which farmers are encouraged to learn from each other. A farmer with unsatisfactory results will try to learn from a successful farmer.

Not only the participant farmers in this research, but also farmers living around the pilot farms, started to ask successful farmers how they managed to maintain farm profitability while using less chemical fertiliser or irrigation water in their fields.

8.8 Conclusion

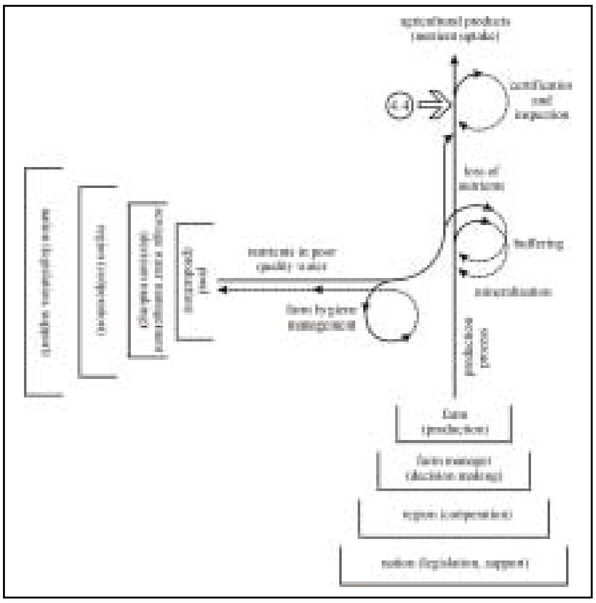
The design procedures followed by the research have indeed improved the practices of most farmers. Even with the many gaps between desired and achieved results that farmers have yet to bridge, progress has been made for a properly functioning use of treated sewagewater in irrigated agriculture. About 29000 m^3 / ha of water, and 112.7 kg / ha N, 13.2 kg / ha P, 31.3 kg / ha K was saved during application of the prototype for the first year, and there was a gain of 2485.76 JD / Ton in the pilot farms.

Designing as done in the first stage of this project made clear that new methods are required, as current methods have become redundant, and farmers' experiences are as important as laboratory-related data. Farmers are more than empty baskets into which scientists only have to pour their knowledge. Designing helps to connect farmers and scientists, and prototyping according to the methodology of Vereijken brings farming close to what policymakers and the society at large is demanding.

Application of the prototypes in practice showed that farmers, even when they are interested and involved, need a lot of experience and data. Initial results from 2000 - 2001 clearly show that our design needs further improvement by progressive retesting procedures. Initial results also reveal the impact of former conventional farming methods. Farmers gained a lot of understanding about the damage caused by current agro-technological methods to relevant natural resources, as well as to their future prospects of farming. Many retesting cycles are required to neutralise the negative impacts of current agro-technological methods.

The prototypes help to create *buffering soil conditions*. Hence nutrient residues from treated sewagewater will be captured and reused for subsequent production cycles. *Disease management* becomes imminent due to decreased nutrient richness on the production site. Plants become vulnerable. The farmers need to spray less. Equally, farmers who refuse to take in treated sewagewater due to indications that it is contaminated with hazardous micro-organisms, are able to do so. But this is the case only when, on the one hand, treated sewagewater producing institutions monitor their effluents and inform farmers about their results and, on the other, farmers have technical methods at their disposal to keep supply tubes closed.

Chapter 9 – Strenghts and weaknesses of prototypes



For Jordan, prototyping represents an entirely new method of conducting research. There are two reasons for this. Firstly, farmers themselves have to play an important role in the establishment of new forms of management and organisation. Secondly, Jordanian scientific researchers have little or no experience with prototyping research in terms of its inherently holistic approach. The prototypes that were developed in the three zones between the As Samra treatment plant and the Jordan River in the course of this project could therefore, with respect to their further development, be hindered. Whether this will actually be the case depends upon the self-confidence of the producers in question as well as on the way in which prototype farms are received by their respective surroundings at large.

This chapter examines the strengths and weaknesses of the prototypes designed in general terms in Jordan. Based on the results accruing from this examination, a concept for government policy is formulated aimed at maintaining and strengthening promising forms of treated sewagewater using farms in Jordan. This general examination will make clear that the certification, quality control and labelling of agricultural products originating from farms already prototyped have a determinative role in deciding whether existing prototypes should be further and more comprehensively improved, or whether other farmers who have not yet done so should switch to redesigning their respective farms.

9.1 Method used

During small meetings it was ascertained how farmers themselves assessed their prototypes. This question was also posed on an individual basis (farmers, policy-makers, researchers). It became clear that getting people together and, moreover, encouraging them to discuss matters which they do not (yet) dare to speak openly about, was by no means easy. Farmers who had not participated in prototyping activities but who had nevertheless followed the development of prototypes in their areas with keen interest were sometimes invited to these small meetings. The question was a simple one: “What positive and negative aspects do you see concerning the prototypes developed in the course of the project?” Discussion was conducted in three rounds. The first round considered their personal answer to the question. Subsequently, the discussion centred upon the question when this was posed in terms of socio-environmental surroundings at large. Lastly, there followed a discussion focusing on the skills and techniques necessary for the maintenance and development of prototypes.

An inventory was made of all responses to the question and these were subsequently grouped.

Partly on the basis of the results given above use was made of literary sources to determine to what extent the collected responses and reactions were ‘real’ in the sense of having real indicative value. We wished to discover whether or not prototyping in other countries had given rise to similar impressions. Such comparative information was important in terms of enabling a better evaluation of the strengths and weaknesses of prototypes in Jordan. The operative issue in this connection was to determine which of the reactions were inherent to a design process generally and which had to do specifically with the Jordanian case in particular.

Finally, possibilities for the further development of treated sewagewater using prototypes in Jordan were studied and explored by means of a simple SWOT analysis[2]. The results of this analysis were formulated in terms of desired (as intended to be supportive) government policy, research and extension services.

9.2 Strengths and weaknesses according to the farmers

During the many discussions with farmers it became apparent that they were initially unwilling to talk openly about their own results and experiences with prototypes. Only later, when it was clear that there was no question of the discussion being in any way a ‘test’ or some sort of ‘examination’, were they willing to speak more freely. This guarded reticence in itself reflects the fact that farmers are not used to their knowledge or experience being taken seriously. By way of illustration, we cite what in our opinion is a telling enunciation on the part of a farmer. The citation contains words in brackets. These words were inserted by the author and therefore do not form part of the farmer’s remarks as such.

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[2] Strenghts, Weaknesses, opportunities and Threats

> *"I am not independent enough to make my own decisions about what I should do on my farm (autonomy). I also have no money, so I depend on the knowledge and experiences of others, sometimes on the equipment of others, but also on banks when it concerns loans, on the behaviour of buyers, and on what researchers wish to tell me (accessibility). Therefore if the project wants to teach me about how to improve my situation so that I enhance production, then it shouldn't be limited to a single moment but take place for a longer period of time (productivity). People should realise that I can only learn from my farm when I see that I'm making progress, and that will only be proved to me when I see that my farm produces more than the cost of investments I've made. For me, this is real evidence that the new design works. I will also believe more and more in the prototype when I see an improvement in my financial position each year (earning capacity). Only if this is the case can I contribute to the needs of society. I know these needs are about a clean environment, safe water, healthy products or a more diversified natural environment (sustainability). I therefore think that one important aspect has been forgotten in the development of prototypes, the role of the consumer. He demands everything without wanting to pay for it. I produce his food. I can do this in the way the consumer wants but everything has its price. A prototype is therefore a realistic option only with the participation of consumers."*

The citation is of interest because it perfectly demonstrates the criteria set out by Conway (1994). This set of criteria has been placed between brackets in the citation. It was evident that the thought process embodied in the citation consistently recurred, albeit in different words. There appears to be a consensus, then, in the way prototypes are perceived. In other words, prototypes seem to depend for their development not only on what the farmer has achieved at a given point in time, but also sets the design of a farm clearly within the context of a process extended over time. Of importance in this connection is the fact that the farmer considers his autonomy to be the first, and thus presumably most important, argument in terms of assessing the strengths and weaknesses of his new farming design.

Table 9.1shows a summary of the most important remarks heard during the discussions. The remarks are grouped. The summary was then shown to a number of randomly selected but relevant stakeholders (farmers, extension officers, researchers and policy-makers) with a request to indicate whether or not they agreed with it.

Table 9.1 Summary of the strength and weaknesses aspects of prototyping treated sewagewater use in irrigation according to farmers

	Strong	**Weak**
Personal level	• Farmer participation increase. • Involvement of the farmers enhances responsibility instead of possible "wait and see" attitude. • Farmers understand their problems better and know how to priorities them. • Greater understanding of performance of technology under farm conditions. • Expertise and extension become integrated before advising farmers. • Researcher-farmer-extension linkages are encouraged. • Ideas amongst researchers and other stakeholders are easily generated. • Sharing of ideas and opinions. • Farmers' reasons for not following research recommendation are better understood. • Direct exchange of ideas between researchers and farmers. • Getting real feel of farmers' needs.	• Not all the problems can be solved by research, some need to be solve by policy-makers. • No funding for on-farm work. • The technique demand too much time from the farmer, especially during intensive field activities (e.g. sowing and harvesting). • Failure may discourage farmer to try again. • Difficult to match farmer perceptions with scientific principles of objectivity. • Much work involved in data analysis.
Societal level	• Interdisciplinary approach is achieved • Involves active participation of all stakeholders. • Enhance effective technology development and transfer. • Helps in transferring the technology in a cheaper way. • Close interaction with the farmers. • Farmers are co-operative and receptive to technology. • More community-oriented. • Small-scale farmers can be reached on their own premises. • Makes farmers feel part and parcel of the process.	• There are various organizations also bringing versions of on-farm research programs. Farmers become confused, which results in unsolved real problems. • Top-down non-participatory approaches from research stations still exist, as long as station members do not really change their orientation. • Poverty, lack of knowledge, and problems like droughts are limiting factors in the short term. Government support to meet them is essential. • Consumers and traders were not involved.
Special experiences	• Exciting to learn how farmers priorities their needs. • Learning the circumstances and needs of the farmers. • It is more practical and acceptable for the farmers as they participate in the trials. • Farmers' empowerment in problem identification and prioritisation of needs. • Gaps can be easily identified. • Understanding the farmers we are working with in terms of socio-cultural beliefs. • Expose researchers to problems on the ground. • Has made us understand why top-down approach failed. • Better understanding of farming community and improved ability to define research agenda.	• Farmers expect more than just technologies to be delivered. • Most farmers need time to understand the approach and the concept. • Monitoring, control and evaluation is hard job in Jordan. • The system is good but making the available is difficult for participants in Jordan. • Field schools are needed. • Demonstration farms must be created.

The following two citations show that farmers who had indeed participated in the project and who could, after one year, form a judgement about the results achieved with respect to their new working methods, clearly saw positive potential.

> *"I have worked in farming for about 25 years. In the past I used to irrigate my fields with fresh water from a stream close to my fields without any problems. Since the water situation changed in this region, treated sewagewater was discharged into the stream and became the only source of water we had to irrigate our fields. Problems started to appear, like diseases and ponded areas with a bad smell and scummy materials, which destroy the crops grown. This makes us change the seedbed every 3 years instead of 6- 7 years as in the past. We thought that treated sewagewater was the cause of these problems. But after working together, I understand that the cause of the problem is how to deal with, or manage, this kind of water quality. Adopting the Water Management method in the prototype helped me to irrigate my fields to optimum crop water requirements. There is no more ponding or scummy materials, and the diseases are minimised".*

and

> *"All farmers in the Middle Jordan Valley depend on chemical fertilisers for crop production. The more fertiliser added the higher the yield will be. This year, by adopting the Nutrient management method, I saved about 500 JD on chemical fertiliser usage and I still have the same production, or a little lower, than last year. The difference in crop production can be compensated by a reduction in the cost of chemical fertilisers used". He continues by saying: "Next year I will continue with this strategy not only because it lowers the costs of production but also because it is safer for my farm and the environment".*

Farmers thus judged the success of their prototypes with reserve. On a superficial level, the cause of this would seem to lie in their scepticism concerning the implications of research for their farms. On a deeper level of consideration, however, it was clear that the farmers were nevertheless able to address issues using very fundamental arguments, and proofs of the fact that prototyping, also in Jordan, has initiated something that engages the interest of farmers.

9.3 Strengths and weaknesses of prototypes as compared with cases outside Jordan

Table 6.1 showed a summary of cases studied abroad in respect of Jordan. The cases in question were selected because they were deemed to exhibit, in different ways, similarities with the situation of farmers in Jordan. It became evident from desk research that application of the prototyping technique is bound to certain limiting conditions. Leeuwis (1999) is of the opinion that prototyping in situations in which farmers are extremely dependent upon their surroundings at large requires modifications and adjustments. From the preceding paragraph, it does indeed seem to be the case that farmers consider the scope to function autonomously to be of importance. The question thus arises whether prototyping as applied in this project did not force farmers too much into a straitjacket.

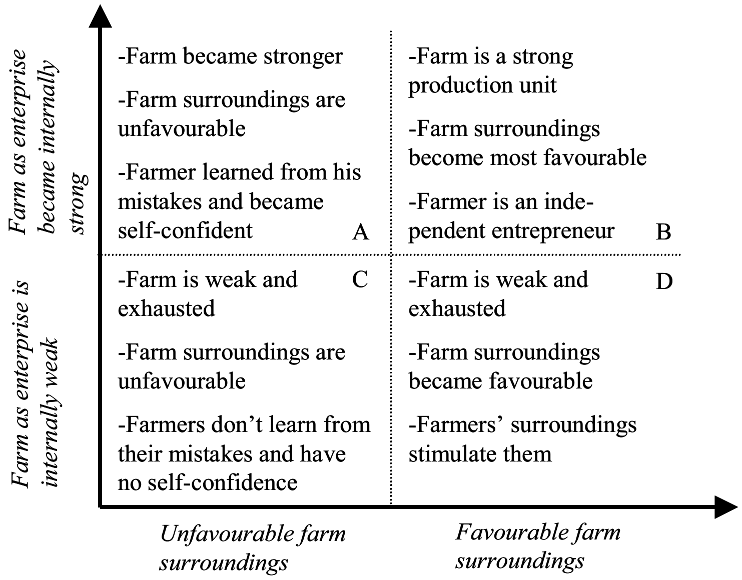
Discussions with farmers that had participated in the project made clear that, one year after the project's conclusion, only some of them had continued developing the design in full accordance with the indicated method. To the question "Why?" there invariably followed an answer making reference to a "dependence on others" and "insufficient access to knowledge and information". The suggestion to redress the situation by pooling information (exchanging experiences) was often dismissed by reactions like "I do not want to advertise my lack of success." Furthermore, "farmers teaching farmers" as a point of departure for prototyping in Jordan is apparently hindered by obstacles of a socio-cultural nature. Van Schoubroeck (1999) demonstrates that adequate governmental stimulation measures can overcome such obstacles. The conclusion that can be drawn with respect to this last point is that government should create a context within which prototyping producers acquire the courage and power to persist on the road thus taken. How this facilitating role might be achieved in practical terms should be made apparent by the next SWOT analysis.

9.4 Developmental potential of prototypes

A SWOT analysis is a quick method of providing insight into the immediate and future situation of an organisation. The operative starting assumption is that the situation of every organisation is the net result of its own strengths and weaknesses (Holling, 1978). A company or enterprise is strong when it can be said to function effectively, flexibly and efficiently in an intrinsic fashion, and successfully translates external circumstances and threats into potential for its own constructive development. We will now look first at the results of a SWOT analysis. This will be followed by a more precise specification of possibilities for the further development of prototypes.

9.4.1 *SWOT analysis*

Figure 9.1 sets the potential of a prototype on the abscissa (*x* axis) and the threats along the ordinate (*y* axis).



Farm as enterprise became internally strong	-Farm became stronger -Farm surroundings are unfavourable -Farmer learned from his mistakes and became self-confident A	-Farm is a strong production unit -Farm surroundings become most favourable -Farmer is an independent entrepreneur B
Farm as enterprise is internally weak	-Farm is weak and exhausted C -Farm surroundings are unfavourable -Farmers don’t learn from their mistakes and have no self-confidence	-Farm is weak and exhausted D -Farm surroundings became favourable -Farmers’ surroundings stimulate them
	Unfavourable farm surroundings	*Favourable farm surroundings*

Figure 9.1 SWOT analysis of the prototypes developed during the project in question. A,B,C and D are quadrants that each reflect developmental potential for prototypes. The difference between A and D is that in A the farmer was the point of impact. He learned to learn from his mistakes and stimulated the creation of a farm with better production conditions. He could do so without help of government or sector. He just needed coaching. In D the surroundings of the farm (government, market, trade organisation, sector) was the point of impact. Once the farmer feels himself stimulated by his surroundings he starts to understand that he must change as long as he wants to continue his farm.

Figure 9.1 shows four developmental situations:

- Quadrant C reflects a situation in which a prototype is not able to develop on its own strength while simultaneously countering oppressive factors (the absence of stimulating marginal conditions in the enterprise’s environment). In such a situation, prototyping activity has to continue for a time under supervision of the facilitator. It is our opinion that this quadrant encompasses the farms that have not yet been redesigned: the bulk of Jordanian family farms, but also those farms that only started prototyping during the project in question. This latter category is thus currently engaged in leaving quadrant C and moving towards quadrant A. The starting position of the enterprise is thus inadequate and a stimulating environment is absent. Barring any change, farms in quadrant C are doomed to survive only marginally. That is the present situation of most Jordanian family farmers.

- Quadrant D shows a situation in which a producer, stimulated by an active government or by the involvement of researchers, successfully adapts his farm to meet current demands. The producer is, as it were, challenged to transcend his blind alley situation and with the help of others implement change. This is the type of situation we see in Europe for example. The EU maintains a policy of stimulation aimed at encouraging farmers to produce in a more sustainable manner. In this case the motive impulse does not originate from the farmer himself but is more or less 'enforced' by a government that desires change with regard to certain forms of land use.

- Quadrant A shows a situation in which a farmer (supported by a facilitator) redesigned his farm in successive stages autonomously and from within his own enterprise according to his own objectives and considerations. Quadrant A therefore comprises significantly improved farms. These farms, however, are unable to counter their stimulus-poor environment on their own steam. To this end the producer has to develop sufficient self-confidence. We see this situation, for example, in the case of organic farmers. This group of producers converted their farms and farming practices as a result of self-articulated concepts (Conford, 2001). But owning and operating such a farm does not mean automatic market support for the enterprise. It is for this reason that we see a number of governments undertake efforts to reward such farms by stimulating potential for remunerative 'green services' or by the stimulation of certification and appropriate legislation.

- Quadrant B reflects a situation in which farms possess an intrinsically outstanding structure of production, adapted to both market demands and to those of society at large, as well as an excellent form of 'communication' with the market. Such farms no longer require government: the operation of market forces is the order of the day. In this situation the farmers have an income, the land is used sustainably and consumers can have confidence in the health and safety of products. An example of this situation is the organic farmers who have organised themselves collectively. In Germany, the Netherlands, Switzerland and Denmark such farms have shown themselves capable of maintaining a remunerative existence while complying in full with the demands of sustainability (Goewie, 2000).

9.4.2 Policy perspectives

Given the reactions of the farmers and in view of the SWOT analysis, it is now becoming increasingly clear that work in the project focused above all on the transition from quadrant C to A. In any case we only worked on strengthening the internal structure and working method(s) of the prototype, irrespective of the potential offered by the respective environments of our farms. The animating principle of the WASTVAL project is aimed at the achievement of a situation as given in quadrant B. In order to be able to take a substantive step in this direction the wider environment shall have to provide stimuli. Such stimuli include, among others, governmental stimulation measures, more attention on the part of researchers for farmers, and the stimulation of communication – in its various forms – with the market. Because Jordanian farmers cannot exert much influence in general they cannot, concomitantly, influence governmental stimulation policies, research institutes or those providing extension services. For this reason the further development of prototypes will once again have to be linked directly to the farmer and his farm, the only points of contact available to him. It is our opinion that the best chance of avoiding disjunction lies in the development of a certification, quality control and labelling system for products originating from farms using treated sewagewater (Zimmerman, 1998).

Figure 9.2 shows the SWOT analysis again, but this time indicating the movements necessary to encourage more farms to use treated sewagewater. In this case it concerns the strengthening of prototypes that have already been designed and new prototypes that have as yet to be made.

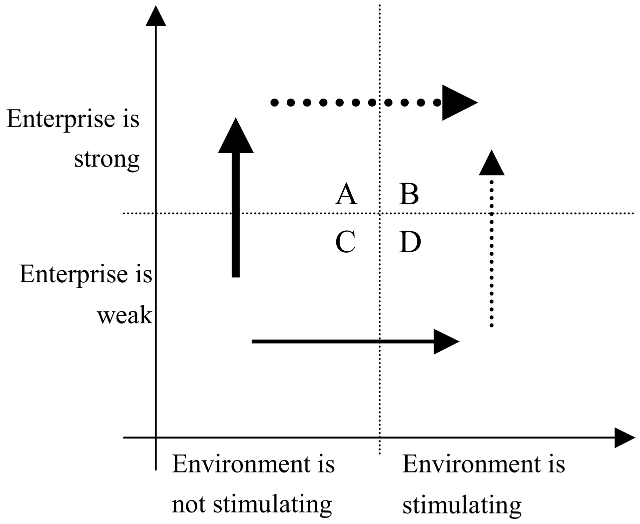


Figure 9.2 shows the movements that could be made by prototypes in the course of time to strengthen existing prototypes and get more prototypes in the research area (topographical designation) up and running. The arrow from C to A indicates the movement made during the research in question. The dotted arrow from A to B indicates what the prototypes in our research area should experience as a result of environmental stimuli. The movement from C to D represents what the government could 'enforce.' Farmers that do not have a good starting position can be encouraged (systems of reward) to use treated sewagewater permanently.

Figure 9.2 demonstrates clearly what policy is desirable in terms of the further development of prototypes and the creation of new prototypes. If nothing happens in this respect, it may be assumed that what has thus far been achieved will revert to the old and undesirable situation as given in quadrant C.

The desired policy impulses are therefore the following:

- The movement from C to A becomes supported by ongoing research on prototypes centring upon the development of powerful soil and crop protection cycles in respect of which dependence upon synthetic fertiliser and pesticides respectively is minimal or negligible. The management of the farm as a whole improves in proportion to the basic cycles of the farm becoming more manageable. This is possible through the development of carefully directed farming systems research programmes. Jordanian research and development policies should to this end give farming systems research a higher priority.

- Giving the area with already developed prototypes some embedding supports the movement from A to B. This can be done with the aid of, among others, demonstration farms, certification, quality control and labelling systems. The producers of such prototypes thereby acquire increased self-confidence and attain a certain measure of autonomy. The government should contribute to this process by developing relevant laws and regulations aimed at defining good agricultural practice. The government could also contribute to the development of regional exhibition farms.

- The movement from C to D become enabled by a pro-active stance on the part of government, research institutes and extension services. Farms should be ‘forced’ to improve their structure and working practices. A powerful research stimulation policy, laws and regulations that discourage the use of synthetic external inputs and forms of subsidy are necessary. Such policy will result in convincing evidence concerning the potential of prototypes using treated sewagewater. Also here, the presence of exhibition farms would be very good. Producers would thereby acquire evidence that might convince them.

- That the movement from D to B be enabled through farms discovering how they can translate challenges and threats accruing from their respective environments into potential for their own further development. The stimulating impulses in this case are chain management and the organisation of producers. Farmers need to be supported in their efforts to become better organised. Field schools and trade organisations serve as good instruments to give farms access to the market.

9.4.3 Certification

It is clear by now that the road taken from C to A will only carries on into quadrant B if the activities of prototyping producers are henceforth also aimed at certification.

Certification schemes are translations of formal legislation, established in national and international laws. Monitoring the safety and authenticity of organically cultivated products in the EU, for example, is governed by a law. This law specifies precisely what an organic product is as well as the requirements, in terms of public health, the environment or animal welfare; it must be in accordance with. Regulations concerning the safety of new (crop) breeds are covered in legislation pertaining to agricultural quality. The so-called certification schemes come into existence when such laws and regulations are translated into a certain systematic which field inspectors can then use to conduct on-the-spot checks to determine whether or not market products meet all legal requirements.

Currently, there is a global demand for certification schemes and they are indeed being implemented worldwide. Exporters are likely, certainly in connection with arrangements made within the WTO framework, to lay down demands *vis-à-vis* the operative production circumstances of the products they purchase. The large retailers of Europe already agreed in 1996, for example, that all products of agricultural origin had as of 2004 to comply with the EUREPGAP (European Certification on Good Agricultural Practise) scheme. The WHO is gradually moving towards a global harmonisation of guidelines addressing the health and safety of food. In this context the Netherlands, for example, designed the HACCP (Hazard Analysis Critical Control Points) scheme to monitor the hygiene levels of food products. In terms of the research areas in question the government, in close co-operation with the agricultural sector, should make a start on such schemes.

The full implementation of such procedures would as yet represent too much of a strain for Jordan. It is therefore worthy of recommendation to teach farmers how they might design their own (private) form of quality guarantees. For prototyping this is not so difficult. The quantified parameters with which the farmers began their prototyping process could serve as the point of departure. As the years progress the criteria could be expanded. Monitoring the implementation of the farmers’ own arrangements concerning quality should be done by independent supervisory organisations. Because the costs for this might be objectionable to farmers, the government could temporarily cover monitoring expenses. In practice, farmers that have already redesigned their farms could continue perfecting their prototypes and be stimulated by a buyer's market in which their products can be distinguished from those of other farms that have not converted.

9.5 Conclusion

Stakeholders involved with the project in question have shown that their prototypes can serve as the beginning of a development towards sustainable, treated sewagewater using farms in Jordan. It is also clear, however, that it cannot work without a stimulating environment. At most, farmers can only progress if they also work for the development of certification systems that they initiate and manage themselves. Figure 9.3 shows the route our prototypes would have to take in policy terms in order to make the acquired result a permanent one.

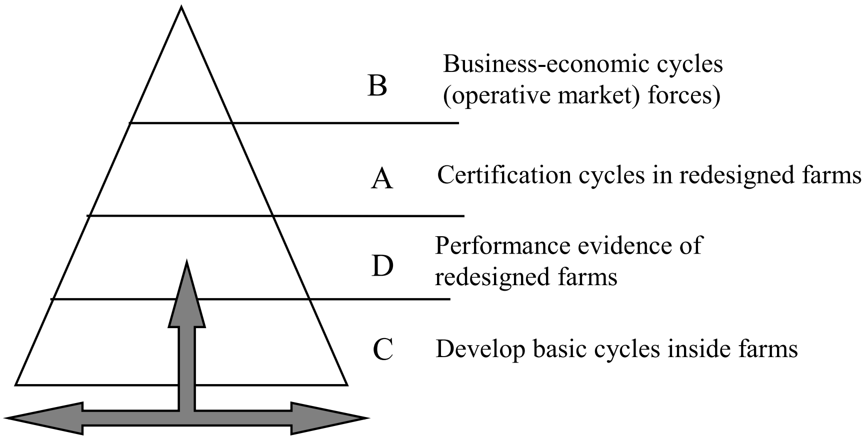
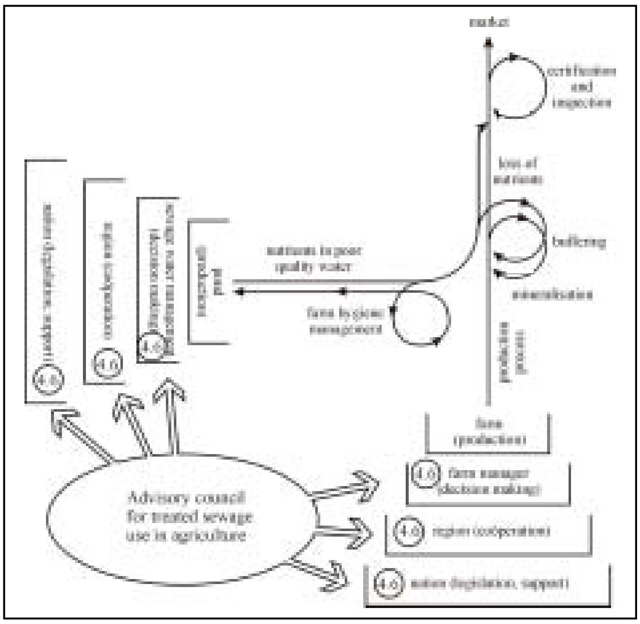


Figure 9.3 The triangle represents the Jordanian farms in the research area of the project in question. The government stimulates a prototype via the following route: redesign the basic cycles of farms (soil and crop protection cycles), and subsequently develop demonstration farms that link convincing evidence to entrepreneurial patterns of behaviour. Following this, develop certification and labelling systems and, finally, allow the producer to operate freely in his respective market. The arrow indicates that the government must help both in terms of increasing the number of prototypes and in terms of rooting these firmly, in order that they may experience sustained growth from situation C to B.

Chapter 10 - Role of stakeholders in safe use of treated sewagewater on farms



The results from this present research demonstrate that treated sewagewater is applicable in farming when the farms concerned redesign their soil management and pest management approaches. Indirectly became shown that the prototypes involved will continue their development when their consumers stimulate them. Such stimulation happens when farmers are able to make their produce discernible with regard to commodities from mainstream, not yet redesigned farms. Farmers must therefore be sustained in their creation of certification, control and labelling systems, indicating that their commodities are safe, despite the fact that for their production treated sewagewater became used. The question now is how to get redesigning activities of the farmers in question continued? This short chapter provides an answer.

10.1 Mainlines for supportive policy making

Chapter 3 assumed that the creation of safe treated sewagewater using farms in the research area of our project requires co-operation between the treated sewagewater producing and using sectors. Co-operation means that both sectors will attune their different goals, methods and end terms for water quality. Co-operation does not start by its own. An independent government must sustain that. We suggest that both sectors come together in the so-called ‘Advisory council for treated sewagewater use in agriculture’. The government must chair the council. Its participants are: three from the agricultural sector (primarily production, trade and retail), three from the treated sewagewater producing sector (influent, processing and storage), three from the government (regulation, inspection and food safety) and three independent specialists (water sanitation, agriculture, certification). The council advices the government and the both sectors involved yearly.

Policy making on treated sewagewater use by farmers could rest on the following issues:

- *Vision*: treated sewagewater is not considered as waste. It is a natural resource. Treated sewagewater supplies the farms with water and essential nutrient for crop production and soil fertility. The amount of nutrients supplied is restricted by what soil and crop system are able to buffer.
- *Objective*: the Jordan government wants to stimulate farmers to use treated sewagewater under the restriction of certification and labeling of end products.
- *Instruments*: the Advisory council for treated sewagewater use in agriculture gives advices about required regulation, standards and investments to stakeholders.
- *Evaluation*: the council produces public reports every year.

10.2 Conclusion from chapter

The treated sewagewater producing and using sectors must work together. They are stimulated to do so when the government establishes an advisory council for the stimulation of treated sewagewater use in agriculture. The co-operation will gradually lead to closed nutrient cycles, prevention of diseases and certification on Jordanian family farms.

Chapter 11 – Conclusion and recommendations from project

Jordan’s industry, drinking water producing plants and agriculture must face **serious water shortages within short time**, when nothing happens. The amount of used sewagewater increases disproportional. That levies a distrain on land use, on quality of environment and biodiversity and on the liveability of the countryside.

The principle ‘**polluter pays**’ could help to reduce the problem. We demonstrated that agriculture is a heavy user of clean or sewagewater and is also a serious polluter of the land. Sewagewater used by farmers contains high concentrations of nutrients and residues of synthetical pesticides. Not recovered substances by crops disappear in soils, water and air. Pollution by using sewagewater becomes aggravated due to diffusion. Moreover, too high nutrient concentrations in production land make crops vulnerable for pests and diseases, evoking a much higher need of pesticides. **Agriculture** therefore must become the point of impact regarding improvement of Jordan’s water balance. Use of treated sewagewater is a realistic option for that: it decreases costs of sewage purification, of purchase of artificial manure and pesticides by farmers and contributes to a cleaner environment.

Permanent use of treated sewagewater in agriculture requires intensive **co-operation between the treated sewagewater producing and using sectors**. Co-operation must be directed on the formulation of end terms for treated sewagewater quality, development of distribution infrastructures and redesign of farming practices in order to protect the land from polluting substances from sewagewater which are bad for food production.

Before the co-operation in question becomes started, researchers and farmers must begin with the **creation of farms that are able to buffer** nutrient surpluses and to prevent infestations by micro-organisms. That process has been mentioned prototyping.

The **prototyping process** of farms must happen through farming system research approaches. The ***goals of the farmer*** are core of the process. The prototyping process must begin and be focussed at

- development of a ***self-buffering soil system***;
- a kind of pest and disease management that the need of synthetic ***pesticides reduces*** and

- the development of a ***certification system*** that makes labelling of commodities from redesigned farms possible.

Prototyping procedures must take Jordanian **farmer's reluctance to co-operate** into account. It appeared that their reluctance has to do with their lack of autonomy (access to information, money, machines, etc.). So, prototyping in Jordan has its limits. Without governmental support redesigning of Jordanian farms will not be easy. Such a support could be given by establishing a national advisory council for stimulation of treated sewagewater use in agriculture. That council brings co-operation between the stakeholders concerned nearby.

An **advisory council** for the stimulation of treated sewagewater in agriculture may support the co-operation between the treated sewagewater producing and using sectors.

Recommendations

When the use of treated sewagewater in Jordan becomes considered seriously then the treated sewagewater producing and using sectors must work together. Such a co-operation could be established when the government starts to undertake the following steps:

- Appoint a national commission for the use of treated sewagewater in agriculture. The commission must advice the government about possibilities and requirements for the general introduction of treated sewagewater as source for irrigation practices in farming.
- Start the set up of demonstration farms (linked to and supported by scientific institutions and extension services) in the three zones between the As Samra treatment plant and the Jordan River and link those farms to the prototypes already developed by the present research project.
- Create a network of field schools where farmers could learn from each other and from results obtained in the demonstration farms.
- Develop for universities and institutions multidisciplinary research programmes between sewagewater specialists and agricultural scientists. The programmes must be based on farming system approaches.
- The government must stimulate regulation that supports the development of sustainable farming (e.g. criteria for use of synthetic agrochemicals).
- Develop capacity building courses at academic and vocational level, institution-wise.
- Consider sustainable use of treated sewagewater by farmers as device for gaining safe, healthy and liveable country sides.

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Appendices

Appendix 3.*

Appendix 3.1. Organisation and working-methods of the treated sewagewater-production sector

The sewagewater producing sector is not easy to manage, since a large number of specified and specialised tasks have to be performed both concurrently and sequentially, and in a planned and coordinated manner, by a variety of professionals, with an array of decisions being made by local, regional, national and international institutions, all of which may exert a direct influence on the sector producing treated sewagewater. Divergent interests and objectives, as well as inter-institutional conflicts and rivalries, further compound the complexity of the process.

Considering the risks associated with the use of treated sewagewater in irrigated agriculture, an adequate institutional framework should always be created to control, supervise and advise on any scheme involving its use, in order to ensure that such use is safe. The institutional framework should be designed to suit local conditions, being well defined and having a clearly specified distribution of responsibilities. The implementation of such an approach will require more sectorial integration and will have considerable implications for organisations, staffing, institutional arrangements and corresponding capacity building. Furthermore, consistent rules and regulations as well as coordination among agencies responsible for sewagewater services should be established to ensure policy cohesion and public support. The treated sewagewater producing sector can therefore be seen as a nested set of management layers consisting of government, regional institutions, treated sewagewater plant managers, and the storage of treated sewagewater in ponds or reservoirs.

The role of government is absolutely crucial. Its primary responsibility will be the provision of a legislative and regulatory framework governing the use of treated sewagewater to protect people against misuse and the inadequate treatment of sewagewater.

Levels of sewagewater treatment and water quality for agricultural irrigation uses are normally governed by health-related regulations or by the type of crop being irrigated. Treated sewagewater plant managers must determine what treatment processes are required to produce an effluent acceptable for potential users. They should inform potential users of all known plans for implementing a system making use of treated sewagewater and obtain the following information during field contact:

- Level of interest in using treated sewagewater,
- Amount and type of current water use,
- Quality constraints applicable to specific uses,
- Site constraints and on-site water system modifications required to use treated sewagewater, and
- Amount of current demand that could be replaced with treated sewagewater.

The concerns, needs, and financial expectations of users must be identified. Group presentations to potential users by technical experts may be useful to disseminate information and answer the potential users' questions and concerns. The initial contact represents the first step in an effort to market the use of treated sewagewater, and results of the survey should be provided to all those participating.

Storage can be used to balance seasonal fluctuations or for operational purposes to equalise the daily supply and demand. Irrigation demand is seasonal, while treated sewagewater supply is nearly uniform year-round. Supply may be sufficient to meet annual demands, but only if seasonal storage is available. The storage (reservoir) manager should know exactly what the needs of the potential users are during the growing season, so that peak demands can be met entirely from the reservoir. The reservoir also functions as an advanced stage in sewagewater treatment. Knowing the required quality of water needed by potential users for the safe use of treated sewagewater in agricultural irrigation helps the reservoir manager to determine how long the treated sewagewater must be kept in the reservoir before distribution to potential users.

Appendix 3.2 Quality control of treated sewagewater in practice

The physical properties and chemical and microbiological constituents of sewagewater are important parameters in the collection, treatment and use of treated sewagewater (Asano et al., 1984). The extent to which sewagewater is a problem and its acceptability for use can therefore be properly assessed if its quality and quantity are viewed as integral parts of an overall policy that includes water, land use, agricultural production, human health and environmental protection. The constituents and the composition of sewagewater vary widely and depend on the composition of the municipal water supply, the nature of wastes added during use, and the degree of treatment applied to the sewagewater (Asano et al., 1984).

The first and the most obvious method of water quality control is to limit the amount of waste discharged into bodies of water and the environment. This type of control can take on a number of forms, including:

- The requirement that each waste producer discharge less waste through, for example, process changes or the removal of at least a specified minimum fraction of the waste prior to releasing the remainder on to land or into natural waters. Removal of waste can be accomplished by a variety of physical, biological, and chemical processes.
- Storing a portion of the treated sewagewater that, if released into natural bodies of water or the environment, would result in a less-than-desired quality. Ponds or reservoirs can be used for treated sewagewater storage. The quantity and timing of stored treated sewagewater discharges on to land areas or bodies of water should depend in part on the waste assimilative capacity of the receiving land area or body of water.
- Piping sewagewater, either prior to or following some treatment, to areas within or outside the region for additional treatment and/or disposal on land or water sites having greater sewagewater assimilative capacities. This alternative also allows for the processing of sewagewater at larger regional facilities, taking advantage of economies of scale in construction and operating costs, as well as on increased operating efficiencies.
- Instream quality improvement from artificial aeration or flow augmentation. Dissolved oxygen deficit concentrations can be decreased by the transfer of oxygen into the water by the injection of air. Increasing the streamflow in periods of low flow by releasing water from upstream reservoirs may also improve the stream quality by dilution and by changing velocities and temperatures, which in turn effect the reaction rates of various quality constituents.

Water quality management objectives are multiple and conflicting. Those in control of activities that generate wastes would naturally prefer to dispose of their wastes at no cost to themselves and, if possible, to others as well. This policy leads to higher profits, if income is being derived from the waste-making activities, or less taxes if the wastes are derived from human settlements such as cities or other municipalities. However, if the discharge of waste does result in added costs (e.g. in environmental damage) elsewhere, those who incur these costs and damage would also prefer not to incur them. They can argue that those who discharge wastes into bodies of water or the environment should pay for the environmental damage caused by that waste or not be allowed to discharge the waste at all. Yet because those who discharge waste are usually not affected by the damage caused by that waste, there is seldom an economic incentive for them to control their discharge. Water pollution is said to be an economic externality (i.e. the activities of some impose costs on others without their consent.). This is the central conflict in water quality management throughout the world.

Because the private market system fails to charge each polluter an amount equal to the damage resulting from their waste discharge, regulatory action is often required. The types of incentives that water quality regulatory agencies have used to compensate for the failure of individual polluters to consider the damage they impose on others are:

- Legislative, including direct regulation, the establishment of treated sewagewater or stream-quality standards, licensing, and zoning;
- Legal, including compensating for damage and fines for violations of the law; and
- Economic, including treated sewagewater charges or taxes, subsidies, accelerated depreciation allowances, and the like.

Whatever the methods used, the objectives should be to achieve a more efficient and equitable allocation of resources from the standpoint of society as a whole.

Appendix 3.3 Organisation and working methods of the agricultural sector

An important role for the national and regional agricultural and irrigation authorities is ensuring that the needs of production agriculture are thoroughly considered in plans to treat and dispose of sewagewater. It is only under a coordinated plan that the agricultural sector can proceed to make long-term use of treated sewagewater in agricultural production safe without such a programme becoming a financial drain on public resources.

Sewagewater treatment at the source of contamination is the most effective means of establishing safe use of treated sewagewater in agricultural production areas. World Health Organisation Guidelines (WHO, 1989) and the World Bank (Shuval *et al.*, 1986a) are in support of such a policy. In most developing countries, as in Jordan, the agencies responsible for treatment do not fully consider the development of safe production areas in establishing their priorities for treatment facility construction. The reason is that many regional sewagewater treatment plans were developed prior to farmer awareness of the safe use of treated sewagewater on his farm and the increased consumer awareness of product safety. In addition the rapid spread of diseases and environmental pollution as a result of treatment plant inefficiency or misuse of treated sewagewater has renewed the need to establish strategies for the treatment and safe use of sewagewater. This need was not considered when initial priorities were set. For example, in 1992 the Khirbet Al Samra treatment plant was overloaded and started to work at only half its rated efficiency. The effluent of the plant is being discharged into the Zarqa River. This discharge, however, pollutes or deteriorates the water quality of the river and risks contaminating the high quality lands along the banks of the river.

The lack of coordinated planning for controlling treated sewagewater discharges will continue to impede agricultural and health programmes designed to establish the safe use of treated sewagewater in agricultural production. Because of this, the Agricultural Ministry should promote the development of an agency, or the strengthening of an existing central agency, that sets discharge standards or sets priorities for the implementation of sewagewater treatment. This agency should draw up a timetable for meeting established goals and review contamination reduction efforts to ensure that these programmes actually meet the goals established. Only with this type of coordinated planning can programmes of the agricultural and health authorities be expected to develop the agricultural resources now being impacted upon by such discharges.

The role of the local service agencies serving the end users of treated sewagewater (farmers) is to ensure a steady flow of the resources (financial, treated sewagewater, seed, etc.) needed to produce a food supply. These local agencies, especially those that supply treated sewagewater, must focus on ensuring that the resource they supply does not affect the safety of the food being produce. An important local group is the canal or irrigation association. They control how treated sewagewater is diverted, distributed and often what other water enters the irrigation supply canals. Because of the importance of contamination that occurs in the irrigation canal network, these associations hold a major key to ensuring a safe water supply. Often those discharging into the irrigation system are also water users or are directly connected with the agricultural system in the area. Each holds a stake in ensuring a safe water supply but often the results of their joint or individual actions are not well understood. These local agencies could act as a focal point for national health and agricultural authorities attempting to treat or promote the safe use of sewagewater.

The private sector and especially the producers (farmers) need to become more involved in seeking solutions to the safe use of treated sewagewater; in problems that are restricting their production. As success is achieved in solving these problems, the costs to the producers and the restrictions on production will diminish. With increased consumer awareness of the need for clean products, there may be an informal labelling of produce. This would be an effort by growers to assure consumers of their product safety. There is a high potential for fraud with any informal system. The Agricultural Ministry needs to standardize the use of certification labels to ensure consumer protection and place a high degree of credibility in the labels being used. The potential for fraud, however, should not diminish the desire of the agricultural and health authorities to use a standard certification label. The economic advantages of using the label should be an incentive for users to avoid fraud.

A primary role of public service (experimental research stations, universities, extension) in food supply is consumer protection. This includes establishing national policies and programmes that promote and provide a safe and readily available food supply. The use of treated sewagewater in agricultural production was identified as one of the chief means of spreading certain diseases (Shuval, 1993). Efforts in the public sector must therefore be strengthened to develop a safe food supply that meets national needs. Some of the considerations to be addressed by public service are:

- Establishing consumer protection standards;
- Regulating health standards;
- Promoting safe production by developing plans to meet national production needs;

- Promote national interest in international markets;
- Minimising negative or non-productive expenditures; and
- Public education

The health authorities should set the boundaries and limitations for acceptability, such as the WHO Guidelines (WHO, 1989), and the role of the Agricultural Ministry should only be to implement programmes that promote safe agricultural production within the limitations established by the health specialists. The health authorities carry the primary role in setting the health standards for water utilised for irrigation. The present standard as described in the WHO Guidelines should remain the goal of the Agricultural Ministry. The Agricultural Ministry should evaluate, however, whether national production goals can be achieved while meeting this standard. If clear evidence is available indicating that national production targets cannot be met, or that negative economic conditions will result, the Agricultural Ministry needs to consult with the health authorities regarding a temporary modification to the regulation. It is strongly felt that the regulation may be very restrictive for existing conditions in many developing countries and that the Health and Agricultural Ministries will need to evaluate closely the data collected during a programme monitoring water quality.

Continuing high disease incidence in developing countries will keep the focus on crop production with treated sewagewater. International pressure is also being exerted as countries importing food from developing countries are requiring more restrictive health protection and product hygiene standards. Because of the increased emphasis on food safety, an effective approach to complement or substitute for a crop restriction programme would be to develop a programme that assures buyers that they were purchasing a high quality product or a product that was produced in a safe environment. Because the market demand for vegetable products will increase, efforts to educate and focus the consumer on the need to use a safe product should be done at the same time as a programme is undertaken to certify that the product was produced in a safe environment. This uses market pressures to force producers to use sanitary conditions when growing vegetables or other high-risk crops.

Appendix 7.*

Appendix 7.1 Salt tolerance of crops [a] (Mass, 1984)

Crop type	Electrical conductivity of saturated soil extract		Osmotic potential of soil solution at field capacity		
	Threshold (dS/m)	Slope (% per dS/m)	Threshold (bar)	Slope (% bar)	Rating
Sweet Corn	1.7	12	1.3	14	MS [b]
Barley	8.0	5.0	6.6	5.5	T [c]
Alfalfa	2.0	7.3	1.5	8.4	MS
Apricot	1.6	24	1.2	29	S [d]
Tomato	2.5	9.9	1.9	12	MS
Cucumber	2.5	13	1.9	15	MS
Pepper	1.5	14	1.1	17	MS
Cabbage	1.8	9.7	1.4	12	MS
Potatoes	1.7	12	1.3	14	MS
Onion	1.2	16	0.9	19	S
Lettuce	1.3	13	1.0	16	MS
Spinach	2.0	7.6	1.5	8.8	MS
Radish	1.2	13	0.9	16	MS
Carrots	1.0	14	0.7	17	S
Strawberry	1.0	33	0.7	41	S

[a] These data serve only as a guideline to relative tolerance among crops. Absolute tolerances vary depending upon climate, soil conditions and cultural practices.

[b] MS means moderately tolerant

[c] T means tolerant

[d] S means sensitive

Appendix 7.2 Crop tolerance and yield potential of selected crops as influenced by irrigation water salinity (EC_w) or soil Salinity (EC_e) [a] (FAO, 1985)

Crop type	**Yield potential** [b]									
	100%		90%		75%		50%		0% [c]	
	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w
Sweet Corn	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Barley	8.0	5.3	10	6.7	13	8.7	18	12	28	19
Alfalfa	2.0	1.3	3.4	2.2	5.4	3.6	8.8	5.9	16	10
Apricot	1.6	1.1	2.0	1.3	2.6	1.8	3.7	2.5	5.8	3.8
Tomato	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0	13	8.4
Cucumber	2.5	1.7	3.3	2.2	4.4	2.9	6.3	4.2	10	6.8
Pepper	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4	8.6	5.8
Cabbage	1.8	1.2	2.8	1.9	4.4	2.9	7.0	4.6	12	8.1
Potatoes	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Onion	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9	7.4	5.0
Lettuce	1.3	0.9	2.1	1.4	3.2	2.1	5.1	3.4	9.0	6.0
Spinach	2.0	1.3	3.3	2.2	5.3	3.5	8.6	5.7	15	10
Radish	1.2	0.8	2.0	1.3	3.1	2.1	5.0	3.4	8.9	5.9
Carrots	1.0	0.7	1.7	1.1	2.8	1.9	4.6	3.0	8.1	5.4
Strawberry	1.0	0.7	1.3	0.9	1.8	1.2	2.5	1.7	4.0	2.7

[a] Adapted from Mass and Hoffman (1977) and Mass (1984). These data should only serve as a guide to relative tolerance among crops. Absolute tolerances vary depending upon climate, soil conditions and cultural practices.

[b] EC_e means average root zone salinity as measured by electrical conductivity of the saturation extract of the soil, reported in deciSiemens per meter (dS/m) at 25 ^{0}C. EC_w means electrical conductivity of the irrigation water in deciSiemens per meter (dS/m). The relationship between soil salinity and water salinity ($EC_e = 1.5\ EC_w$) assumes a 15-20 percent leaching fraction and a 40-30-20-10 percent water use pattern for the upper to lower quarters of the root zone.

[c] The zero yield potential or maximum ECe indicates the theoretical soil salinity (ECe) at which crop growth ceases.

Appendix 7.3 Guideline for interpretation of water quality for irrigation (FAO, 1985)

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to Moderate	Severe
Salinity (affects crop water availability)				
EC_w [1]	dS/m	< 0.7	0.7- 3.0	> 3.0
or				> 2000
TDS	mg/l	< 450	450- 2000	
Infiltration (affects infiltration rate of water into the soil)	EC_w=			
SAR [2]		> 0.7	0.7-0.2	< 0.2
0- 3		> 1.2	1.2-0.3	< 0.3
3- 6		> 1.9	1.9-0.5	< 0.5
6-12		> 2.9	2.9-1.3	< 1.3
12-20		> 5.0	5.0-2.9	< 2.9
20-40				
Specific ion toxicity (affects sensitive crops)				
Sodium (Na)				
Surface irrigation	SAR	< 3	3-9	> 9
Sprinkler irrigation	meq/l	< 3	> 3	
Chloride (Cl)				
Surface irrigation	meq/l	< 4	4-10	> 10
Sprinkler irrigation	meq/l	< 3	> 3	
Boron (B)	meq/l	< 0.7	0.7-3.0	> 3.0
Trace elements (see Appendix 5)				
Miscellaneous effects (affects susceptible crops)				
Nitrogen (NO_3-N) [3]	meq/l	< 5	5-30	> 30
Bicarbonate (HCO_3)	meq/l	< 1.5	1.5-8.5	> 8.5
pH	Normal range 6.5- 8.4			

[1] EC_w means electrical conductivity in deciSiemens per meter at 25 °C

[2] SAR means sodium adsorption ratio

[3] NO_3-N means nitrate nitrogen reported in terms of elemental nitrogen

Appendix 7.4 Calcium concentration (Ca_x) expected to remain in near-surface soil-water following irrigation with water of given HCO_3 / Ca ratio and ECw (FAO, 1985)

		Salinity of applied water (EC_w)											
		0.1	0.2	0.3	0.5	0.7	1.0	1.5	2.0	3.0	4.0	6.0	8.0
Ratio of HCO_3/Ca	0.05	13.20	13.61	13.92	14.40	14.79	15.91	15.91	16.43	17.28	17.79	19.07	19.94
	0.10	8.31	8.57	8.77	9.07	9.31	9.62	10.02	10.35	10.89	11.32	12.01	12.56
	0.15	6.34	6.54	6.69	6.92	7.11	7.34	7.65	7.90	8.31	8.64	9.17	9.58
	0.20	5.24	5.40	5.52	5.71	5.87	6.06	6.52	6.52	6.86	7.13	7.57	7.91
	0.25	4.51	4.65	4.76	4.92	5.06	5.22	5.44	5.62	5.91	6.15	6.52	6.82
	0.30	4.00	4.12	4.21	4.36	4.48	4.62	4.82	4.98	5.24	5.44	5.77	6.04
	0.35	3.61	3.72	3.80	3.94	4.04	4.17	4.35	4.49	4.72	4.91	5.21	5.45
	0.40	3.30	3.40	3.48	3.60	3.70	3.82	3.98	4.11	4.32	4.49	4.77	4.98
	0.45	3.05	3.14	3.22	3.33	3.42	3.53	3.68	3.80	4.00	4.15	4.41	4.61
	0.50	2.84	2.93	3.00	3.10	3.19	3.29	3.43	3.54	3.72	3.87	4.11	4.30
	0.75	2.17	2.24	2.29	2.37	2.43	2.51	2.62	2.70	2.84	2.95	3.14	3.28
	1.00	1.79	1.85	1.89	1.96	2.01	2.09	2.16	2.23	2.35	2.44	2.59	2.71
	1.25	1.54	1.56	1.63	1.68	1.73	1.78	1.86	1.92	2.02	2.10	2.23	2.33
	1.50	1.37	1.41	1.44	1.49	1.53	1.58	1.65	1.70	1.79	1.86	1.97	2.07
	1.75	1.23	1.27	1.30	1.35	1.38	1.43	1.49	1.54	1.62	1.68	1.78	1.86
	2.00	1.13	1.16	1.19	1.23	1.26	1.31	1.36	1.40	1.48	1.54	1.63	1.70
	2.25	1.04	1.08	1.10	1.14	1.17	1.21	1.26	1.30	1.37	1.42	1.51	1.58
	2.50	0.97	1.00	1.02	1.06	1.09	1.12	1.17	1.21	1.27	1.32	1.40	1.47
	3.00	0.85	0.89	0.91	0.94	0.96	1.00	1.04	1.07	1.13	1.17	1.24	1.30
	3.50	0.78	0.80	0.82	0.85	0.87	0.90	0.94	0.97	1.02	1.06	1.12	1.17
	4.00	0.71	0.73	0.75	0.78	0.80	0.82	0.86	0.88	0.93	0.97	1.03	1.07
	4.50	0.66	0.68	0.69	0.72	0.74	0.76	0.79	0.82	0.86	0.90	0.95	0.99
	5.00	0.61	0.63	0.65	0.67	0.69	0.71	0.74	0.76	0.80	0.83	0.88	0.93
	7.00	0.49	0.50	0.52	0.53	0.55	0.57	0.59	0.61	0.64	0.67	0.71	0.74
	10.00	0.39	0.40	0.41	0.42	0.43	0.45	0.47	0.48	0.51	0.53	0.56	0.58
	20.00	0.24	0.25	0.26	0.26	0.27	0.28	0.29	0.30	0.32	0.33	0.35	0.37
	30.00	0.18	0.19	0.20	0.20	0.21	0.21	0.22	0.23	0.24	0.25	0.27	0.28

Appendix 7.5 Chloride tolerance of some fruit crop cultivars and rootstock [1] (FAO, 1985)

Crop	**Rootstock or cultivar**	**Maximum permissible CL- without leaf injury** [2]	
		Root zone (Cl_e) (me/l)	**Irrigation water (Cl_w)** [3,4] **(me/l)**
	Rootstock		
Avocado	West Indian	7.5	5.0
	Guatemalan	6.0	4.0
	Mexican	5.0	3.3
Citrus	Sunki Mandarin Grapefruit Cleopatra mandarin Rangpur lime	25.0	16.6
	Sampson tangelo Rough lemon Sour orange Ponkan mandarin	15.0	10.0
	Citrumelo 4475 Trifoliate orange Cuban shaddock Calamondin Sweet orange Savage citrange Rusk citrange Troyer citrange	10.0	6.7
Grape	Salt creek, 1613-3	40.0	27.0
	Dog Ridge	30.0	20.0
Stone fruits	Marianna	25.0	17.0
	Lovell, shalil	10.0	6.7
	Yunnan	7.5	5.0
	Cultivars		
Berries	Boysenberry	10.0	6.7
	Olallie blacjberry	10.0	6.7
	Indian summer raspberry	5.0	3.3
Grape	Thompson seedless	20.0	13.3
	Perlette	20.0	13.3
	Cardinal	10.0	6.7
	Black rose	10.0	6.7
Strawberry	Lassen	7.5	5.0
	Shasta	5.0	3.3

[1] Adapted from Mass (1984)

[2] For some crops, the concentration given may exceed the overall salinity tolerance of that crop and cause some reduction in yield in addition to that caused by chloride ion toxicities

[3] Values given are for the maximum concentration in the irrigation water. The values were derived from saturation extract data (EC_e) assuming a 15-20 percent leaching fraction and ECe = 1.5 EC_w

[4] the maximum permissible values apply only to surface irrigated crops. Sprinkler irrigation may cause excessive leaf burn at values far below these. See Appendix 7.6

Appendix 7.6 Relative tolerance of selected crops to foliar injury from saline water applied by sprinkler [1,2] (FAO, 1985)

Na + or Cl – concentration causing foliar injury [3]			
<5	5-10	10-20	>20
Almond	Grape	Alfalfa	Cauliflower
Apricot	Pepper	Barley	Cotton
Citrus	Potato	Corn	Sugarbeet
Plum	Tomato	Cucumber	Sunflower
		Safflower	
		Sesame	
		Sorghum	

[1] Data taken from Mass (1984)

[2] Susceptibility based on direct accumulation of salts through the leaves

[3] Leaf absorption and foliar injury are influenced by cultural and environmental conditions such as drying winds, low humidity, speed of rotation of sprinklers and the timing and frequency of irrigation. Data preented are only general guidelines for late spring and summer daytime sprinkling

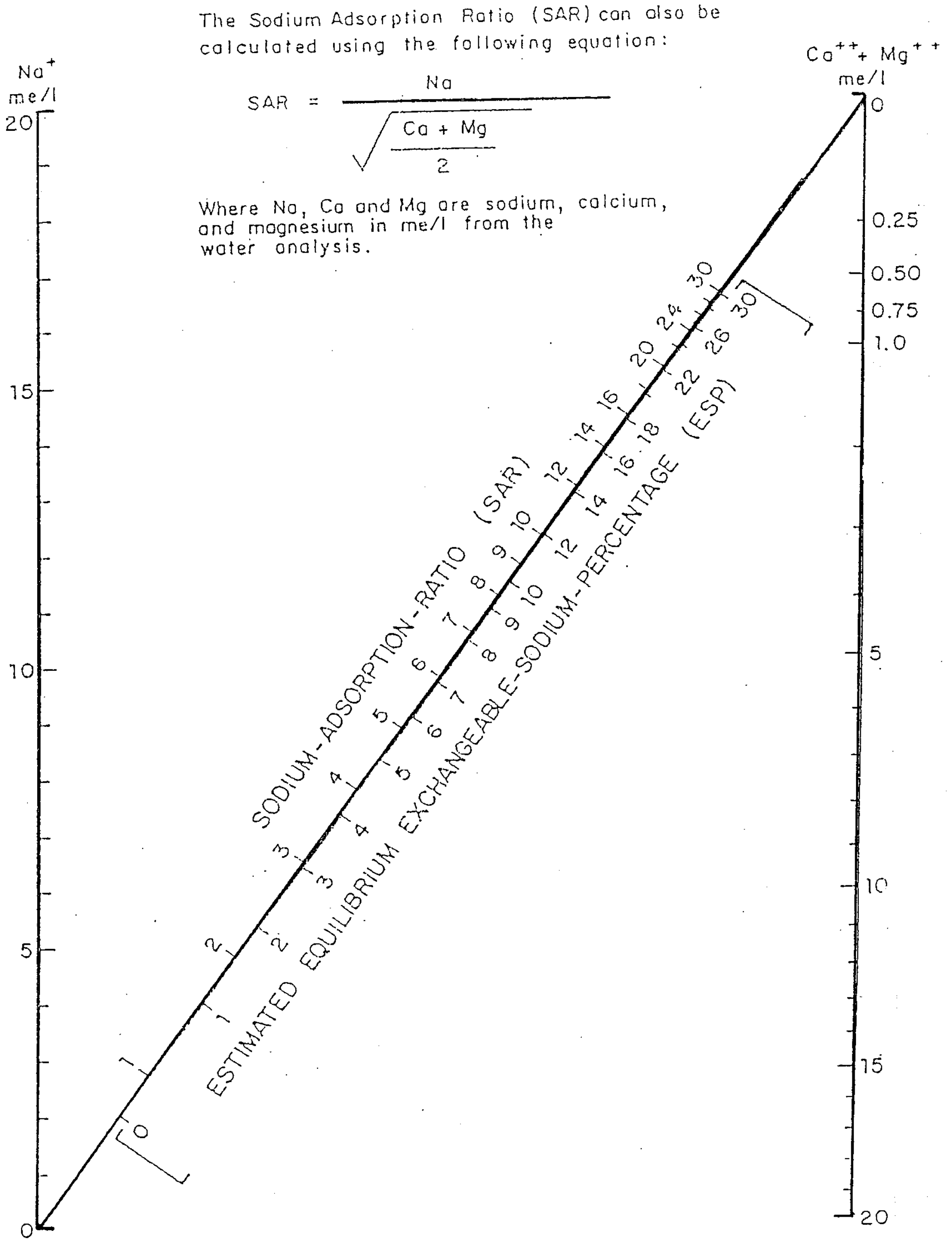
Appendix 7.7 Relative tolerance of selected crops to exchangeable sodium [1] (FAO, 1985**)**

Sensitive [2]	**Semi-tolerant [2]**	**Tolerant [2]**
Avocado	Carrot	Alfalfa
Deciduous fruits	Clover, Ladino	Barley
Nuts	Dallisgrass	Beet, garden
Bean, green	Fescue, tall	Beet, sugar
Cotton (at germination)	Lettuce	Bermuda grass
Maize	Bajara	Cotton
Peas	Sugarcane	Paragrass
Grapefruit	Berseem	Rhodes grass
Orange	Benji	Wheatgrass, crested
Peach	Raya	Wheatgrass, fairway
Tangerine	Oat	Wheatgrass, tall
Mung	Onion	Karnal grass
Mash	Radish	
Lentil	Rice	
Groundnut (peanut)	Rye	
Gram	Ryegrass, Italian	
Cowpeas	Sorghum	
	Spinach	
	Tomato	
	Vetch	
	Wheat	

[1] Adapted from data of FAO-Unesco (1973); Pearson (1960) and Abrol (1982)

[2] The approximate levels of exchangeable sodium percentage (ESP) corresponding to the three categories of tolerance are: sensitive less than 15 ESP; semi-tolerant 15-40 ESP; tolerant more than 40 ESP. Tolerance decreases in each column from top to bottom. The tolerances listed are relative because, usually, nutritional factors and adverse soil conditions stunt growth before reaching these levels. Soil with an ESP above 30 will usually have too poor a physical structure for good crop production. Tolerances in most instances were established by first stabilising soil structure.

Appendix 7.8 Nomograph for determination of SAR value of irrigation water and for estimation of corresponding ESP value of a soil that is at equilibrium with the water (FAO, 1985)



The Sodium Adsorption Ratio (SAR) can also be calculated using the following equation:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

Where Na, Ca and Mg are sodium, calcium, and magnesium in me/l from the water analysis.

Appendix 7.9 Relative Boron tolerance of agricultural crops [1,2] (FAO, 1985)

Very sensitive (< 0.5 mg/l)
Lemon
Blackberry

Sensitive (0.5 – 0.75 mg/l)
Avocado
Grapefruits
Orange
Apricot
Peach
Cherry
Plum
Persimon
Fig, kadota
Grape
Walnut
Pecan
Cowpea
Onion

Sensitive (0.75 – 1.0 mg/l)
Garlic
Sweet potato
Wheat
Barley
Sunflower
Bean, mung
Sesame
Lupine
Strawberry
Artichoke, Jerusalem
Bean, kidney
Bean, lima
Croundnut, Peanut

Moderately sensitive (1.0 – 2.0 mg/l)
Pepper, red
Pea
Carrot
Radish
Potato
Cucumber

Moderately Tolerant (2.0 – 4.0 mg/l)
Lettuce
Cabbage
Celery
Turnip
Bluegrass, Kentucky
Oats
Maize
Artichoke
Tobacco
Mustard
Clover, sweet
Squash
Muskmelon

Tolerant (4.0 – 6.0 mg/l)
Sorghum
Tomato
Alfalfa
Vetch, purple
Parsley
Beet, red
Sugarbeet

Ver tolerant (6.0 – 15.0 mg/l)
Cotton
Asparagus

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[1] Data taken from Mass (1984)

[2] Maximum concentrations tolerated in soil water without yield or vegetative growth reductions. Boron tolerances vary depending upon climate, soil conditions and crop varieties. Maximum concentrations in the irrigation water are approximately equal to these values or slightly less.

Appendix 7.10 Influence of water quality on the potential for clogging problems in localised (drip) irrigation system (adapted from Nakayama, 1982)

Potential problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Physical				
Suspended solid	mg/l	<50	50-100	>100
Chemical				
PH	mg/l	<7.0	7.0-8.0	>8.0
Dissolved solids	mg/l	<500	500-2000	>2000
Manganese [1]	mg/l	<0.1	0.1-1.5	>1.5
Iron [2]	mg/l	<0.1	0.1-1.5	>1.5
Hydrogen Sulphide	mg/l	<0.5	0.5-2.0	>2.0
Biological				
Bacterial populations	max. number/ml	<10000	10000-50000	>50000

[1] While restriction in use of localised (drip) irrigation systems may not occur at these manganese concentrations, plant toxicities may occur at lower concentrations

[2] Iron concentrations >5.0mg/l may cause nutritional imbalances in certain crops

Appendix 7.11 Microbial quality guidelines for wastewater reuse in Jordan

Reuse type	Intestinal nematodes	Faecal coliforms
Unrestricted		
Irrigation of crops to be eaten uncooked.	Not allowed	Not allowed
Irrigation of sports field, public parks.	≤1	≤200
Restricted		
Irrigation of cereal crops, industrial crops, fodder and trees	≤1	≤1000
Localised		
Irrigation of cereal crops, industrial crops, fodder and trees with no exposure of workers and the public	Not allowed	Not allowed
Frequency of testing	>2 per month	>2 per month

Source: Al-Salem, 1992

Appendix 7.12 Recommended microbial quality guidelines for wastewater reuse in irrigation (WHO, 1989*)*

Category	Reuse conditions	Exposed group	Intestinal nematodes [b] (mean no. of eggs per litre [c])	Faecal coliforms (geometric mean no. per 100 ml [c])	Wastewater treatment expected to achieve microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks [d]	Workers, consumers and public	≤ 1	≤ 1000 [d]	A series of stabilisation ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees e	Workers	≤ 1	Not applicable	Retention in stabilisation ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localised irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation.

[a] In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account, and these guidelines modified accordingly.

[b] Ascaris, Trichuris and hookworms.

[c] During the irrigation period.

[d] A more stringent guideline (≤ 200 faecal coliforms/100ml) is appropriate for public lawns, with which the public may have direct contact.

[e] In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

Appendix 8.*

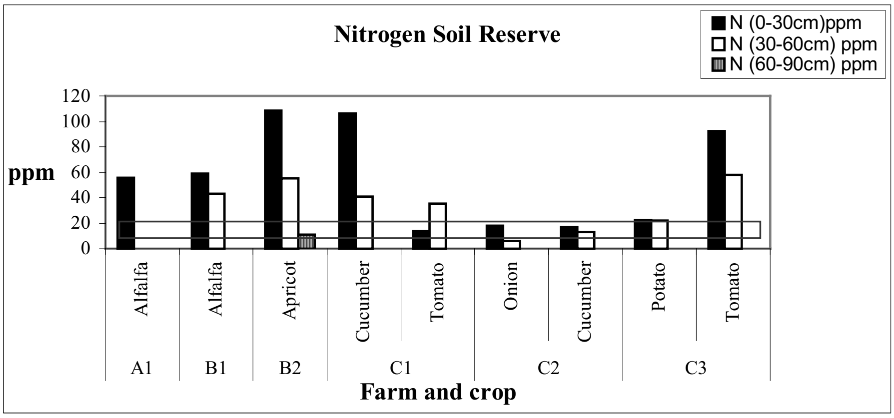
Appendix 8.1 Generalised guidelines for interpretation of plant analysis data

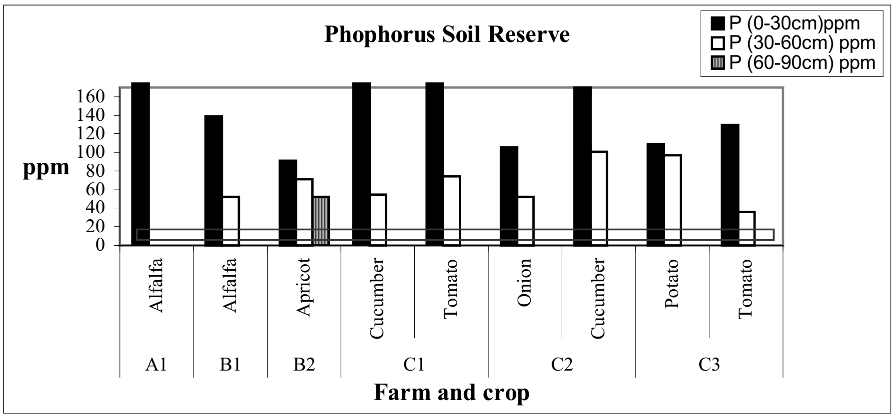
Crop	Tissue sampled	Age, stage or date of sampling	Nutrients	Range in dry matter (percentage)					References
				Showing deficiency symptoms	Low range	Intermediate range	High range	Showing toxicity symptoms	
Alfalfa	Tops	Vegetative	N	< 4.0	4.0-4.4	4.5-5.0	> 5.0		Reuter, 1997
	Leaves	Flowering	P	-------	0.19-0.22	0.23-0.53	-------	----------	Chapman, 1996
	Leaves	Vegetative	P	< 0.20	0.20-0.25	0.26-0.70		> 0.7	Reuter, 1997
	Tops	Harvest time	K	0.14	< 1.70	> 1.80	> 3.0		Chapman, 1996
	Leaves	Vegetative	K	< 1.8	1.8-2.4	2.5-3.8	> 3.8		Reuter, 1997
Apricot	Leaves	Midsummer	N		2.0	3.0	3.5		Chapman, 1996
	Leaves	--------------	N	< 1.7	1.7-2.3	2.4-3.0	3.1-4.0	> 4.0	Reuter, 1997
	Leaves	--------------	P	< 0.09	0.09-0.13	0.14-0.25	0.26-0.40	> 0.4	Reuter, 1997
	Leaves	Mature	K		< 2.0	> 2.0			Chapman, 1996
	Leaves	--------------	K	< 1.0	1.0-1.9	2.0-3.5	3.6-4.0	> 4.0	Reuter, 1997
Potato	Tops	88 days old	N		2.87	3.0			Chapman, 1996
	Leaves	84 days after planting	N		3.2				Reuter, 1997
	Leaves	75 days after planting	P	< 0.05	0.05-0.10	> 0.10			Chapman, 1996
	Leaves	Mid stem	K	1.55-3.15		5.19-6.79			Chapman, 1996
Tomato	Leaves	Harvest	N		2.0	2.2-2.5			Reuter, 1997
	Leaves	Recently mature	P	0.10-0.18	0.18-0.29	0.44-0.90	> 0.90		Chapman, 1996
	Leaves	Harvest	P	< 0.13		> 0.40			Reuter, 1997
	Leaves	April-May	K	0.96-1.23		1.55-3.76			Chapman, 1996
	Leaves	Harvest	K		3.8				Reuter, 1997
Cucumber	Leaves	Harvest	N	3.50-3.99		4.0-5.50	> 5.50		Reuter, 1997
	Leaves	Harvest	P	0.22-0.24		0.25-1.0	> 1.0		Reuter, 1997
	Leaves	Harvest	K	2.80-3.29		3.5-4.5	> 4.5		Reuter, 1997
Onion	Leaves	Harvest	N		1.3	1.5-1.75			Reuter, 1997
	Leaves	Harvest	P		0.20	0.30-0.45			Reuter, 1997
	Leaves	Harvest	K		1.3	1.6-2.2			Reuter, 1997

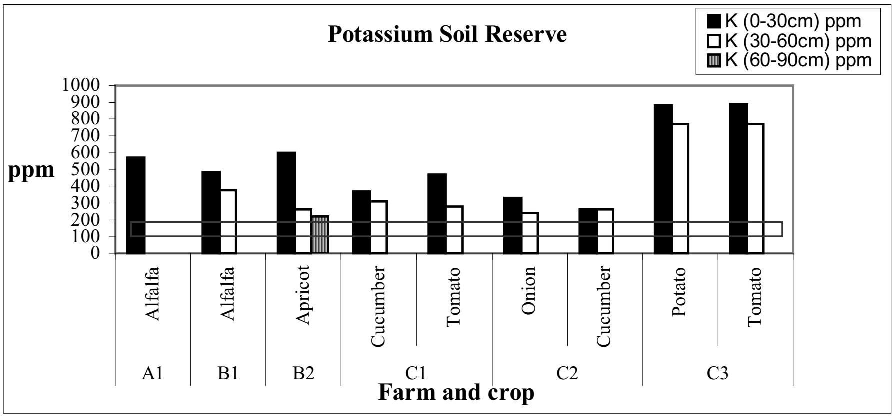
Appendix 8.2 Generalised guidelines for interpretation of soil analysis data

Nutrient	Soil test	Low	Marginal	Adequate
		ppm (= mg/kg)		
Nitrogen	AB-DTPA	< 11	11- 20	> 20
Phosphorus	$NaHCO_3$	< 8	8- 15	> 15
Potassium	NH_4Oac	< 100	100- 150	> 150

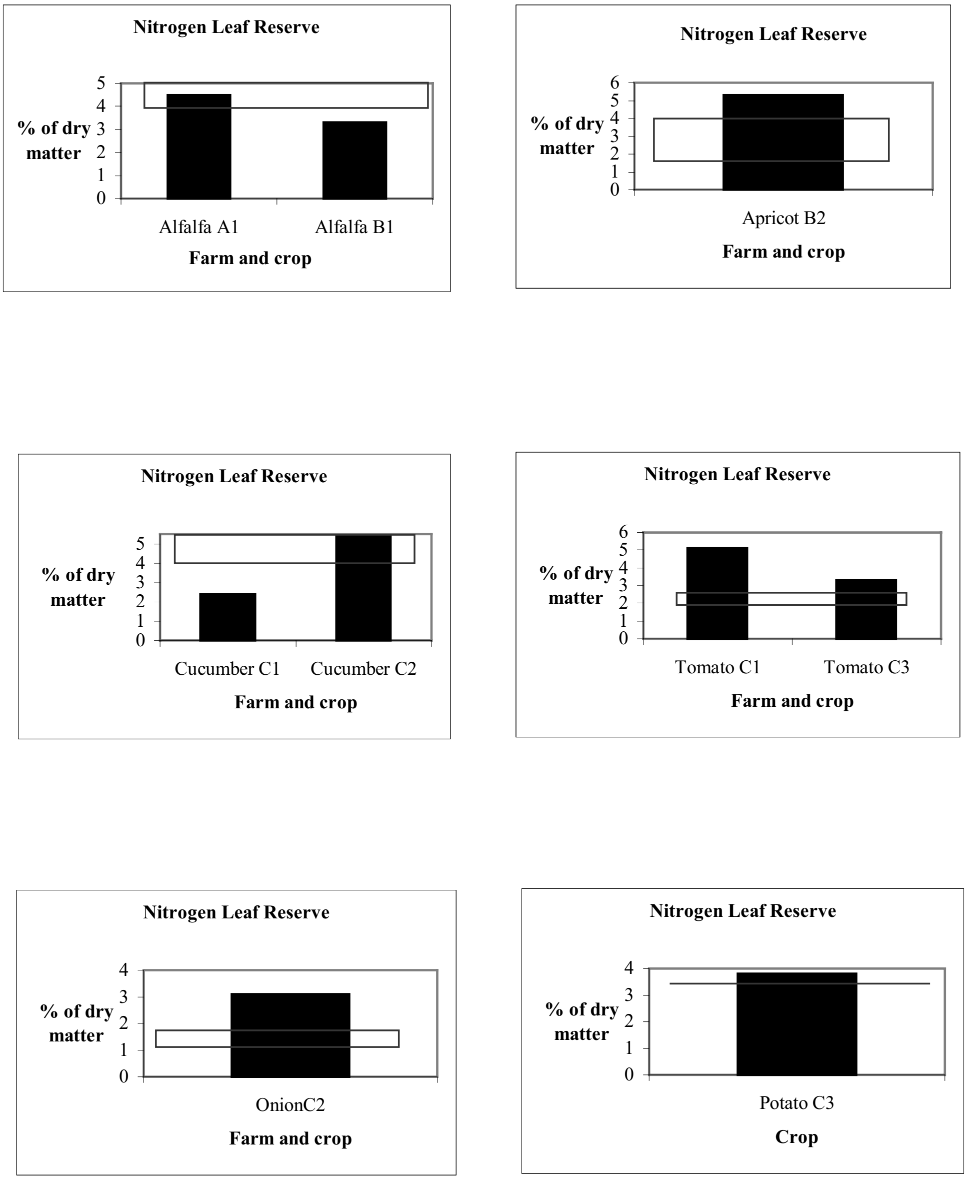
Source: Garabet et al., 1996



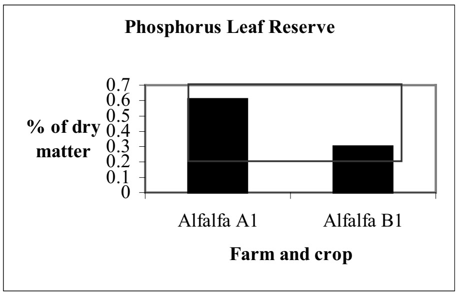


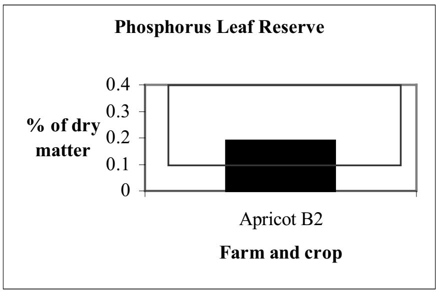


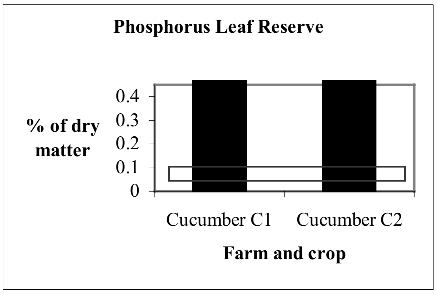
Appendix 8.3 Mineral Nitrogen (N-NO_3 plus N-NH_4), Extractable Phosphorus (P) and Extractable Potassium (K) Soil Reserves at pilot farms in zone A, B and C at 1999-2000 growing season. Vertical columns indicate N-NO_3 plus N-NH_4, P and K values in soil at depth indicated in the legend in part per million (ppm) (1 ppm = 1 mg/kg). Horizontal columns indicate the desired ranges of N, P and K in soil in ppm. These values adapted from Garabet et al.,1996 (see Appendix 8.2).

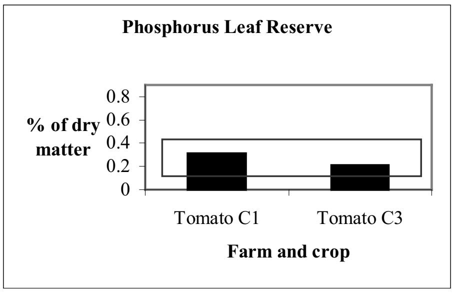


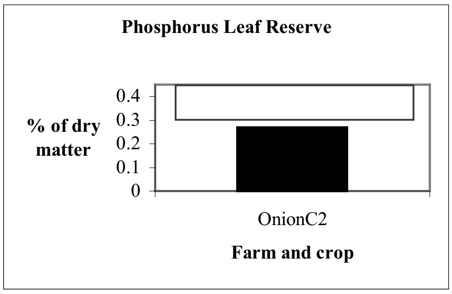
Appendix 8.4 Total Nitrogen (N), Phosphorus (P) and Potassium (K) Leaf Reserves at pilot farms in zone A, B and C at 1999-2000 growing season. Vertical columns indicate the NLR, PLR and KLR values in parts per million)ppm) (1 ppm = 1 mg/kg). Horizontal columns indicate the desired ranges of NLR, PLR and KLR adapted from various resources (see Appendix 8.1).

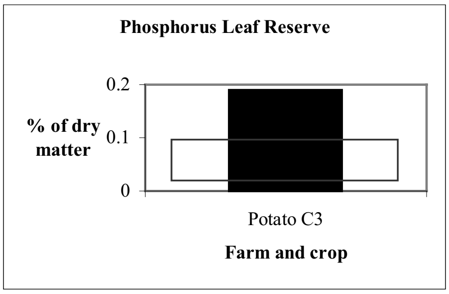












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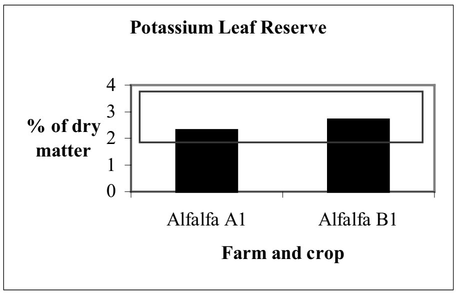

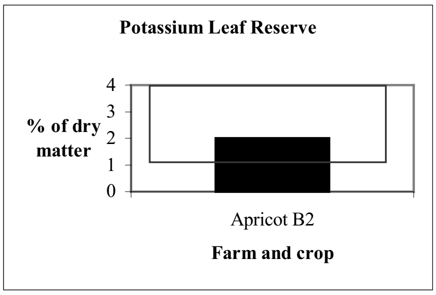

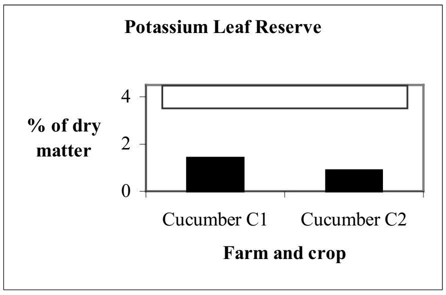

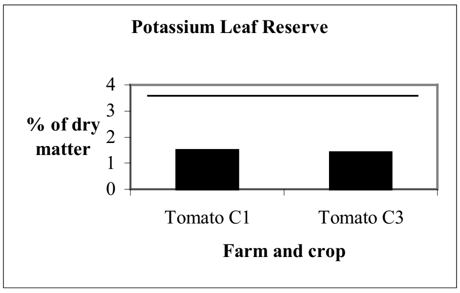

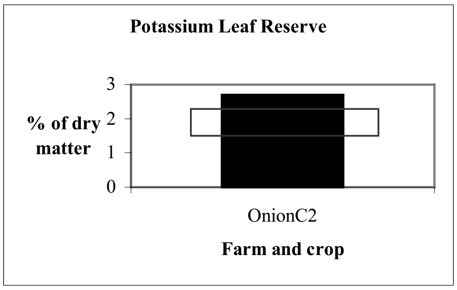

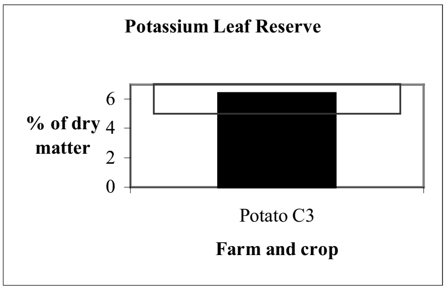

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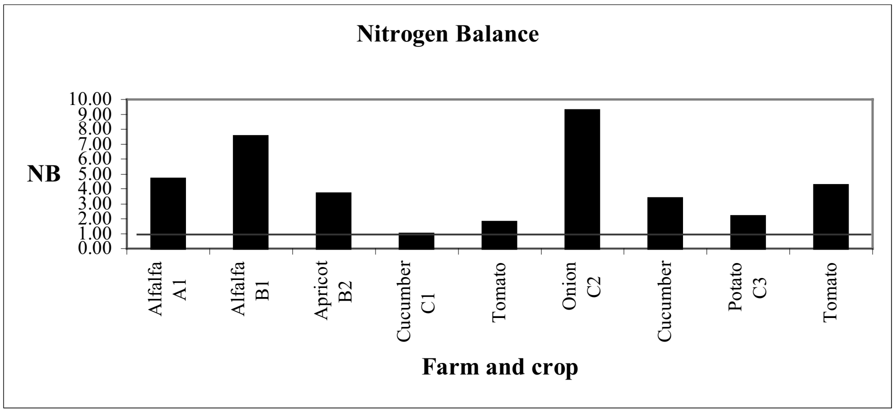
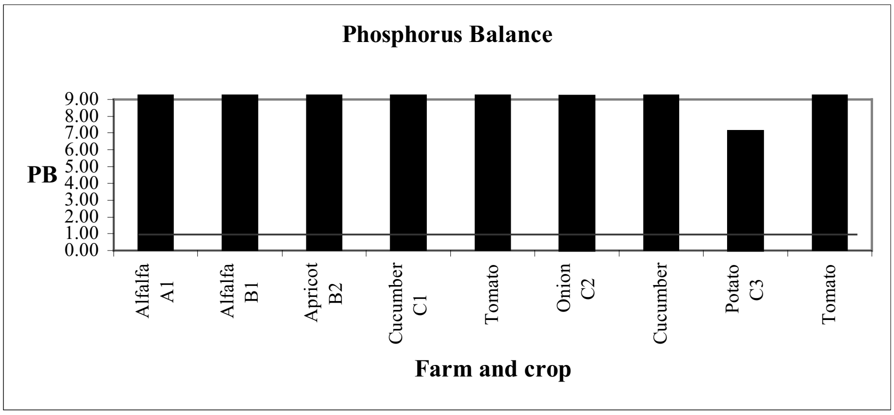
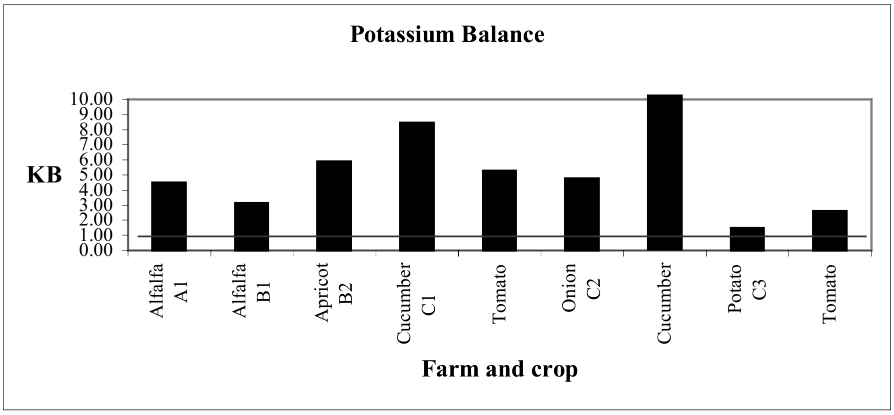
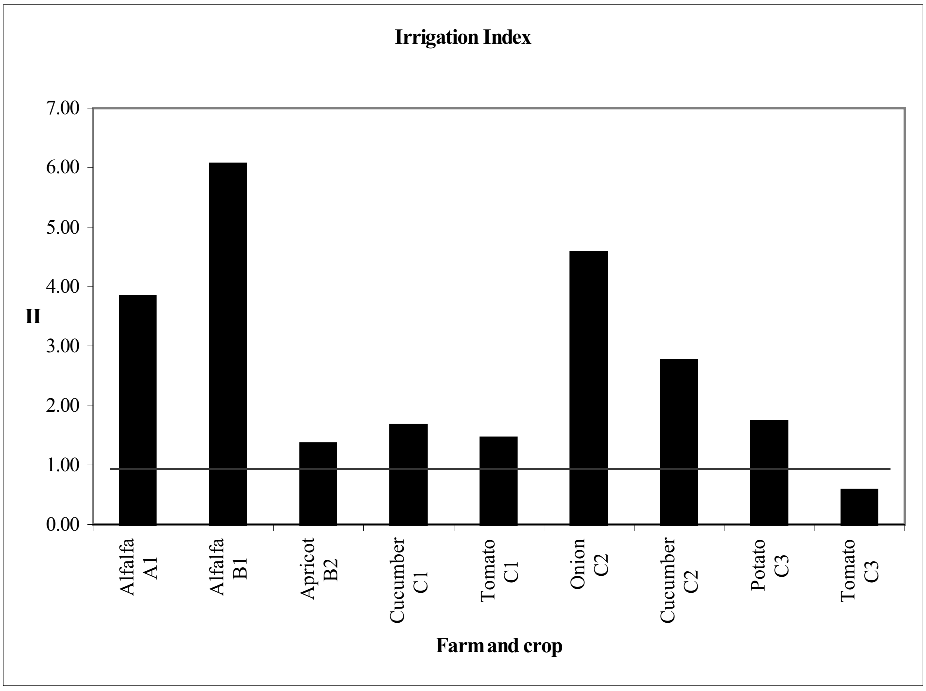






Appendix 8.5 Marcro-nutrient Balances in pilot farms in zones A, B and C in 1999-2000 growing season. Vertical columns indicate the Nitrogen (N), Phosphorus (P) and Potassium (K) balance. Horizontal lines indicate the desired ranges at this stage of the research.



Appendix 8.6 Irrigation Index (II) at pilot farms in zones A, B and C in 1999-2000 growing season. Vertical columns indicate the ratio between water used to water needed. Horizontal line indicates the desired range.

Appendix 8.7 Organisation of measurement of water, soil and plant in the field

Organised measurements in pilot farms, for water, soil and plant analysis and theoretical water requirement of crops are as follows:

A. Water quality analyses

For the collection of data on the nutrient content of the water used for irrigation, semi-quantitative methods were used. This allowed quick observations, which sufficed the objectives of this research. The measurements took place on a weekly basis. At each of the selected farms one water sample was collected, either from the water stream or from the reservoir (depending on the source present). For the first weeks, the amount of N, P and Cl^- in the water was measured on-site, even as the pH and Electrical Conductivity (EC). The amount of K in the sewage –water was analysed in the laboratory. Measuring on-site appeared time consuming and hard, because of hot weather conditions. Therefore, after the first week, it was decided to only collect the water samples. All the analysis where done off-site, in the laboratory. Water samples were collected in drinking water bottles. Gloves were worn for protection. Bottles were rinsed several times before the actual samples were taken. Each bottle was completely filled, in order to prevent change of substances. The bottles were labelled and stored in a cool box during transportation. In the laboratory they were kept in refrigerator till the moment of analysing.

The amount of N was measured in its form of ammonium (NH_4^+) and nitrate (NO_3^-). For ammonium a reagent kit for rapid analysis was used, identifying the amount of NH_4^+ ranging between 0.2-8.0 mg/l through a colour reaction. However, in the whole study area the ammonium concentrations of the sewagewater exceeded these rages to a large extend. As a solution, the water samples were diluted (for zones A and B 50 times, for zone C 25 times) before analysing, resulting in concentrations that fitted the range.

Nitrate concentrations were found using analytical test strips, providing an indication of the Nitrate concentration by colour scale. Amounts of NO_3^- ranging between 10-500 mg/l could be identified. The strip also provided a qualitative indication (-, + or ++) for the nitrite (NO_2^-) content of the water.

The amount of P in the sewagewater was measured in its form of phosphate (PO_4^-) and orthophosphate (Expressed as P_2O_5, this form does not exist in reality and is only a count unit.) Phosphorus concentrations were found using reagent kit for rapid analysis of P, identified the amount ranging between 1.0-49 mg/l through a colour reaction. The two forms of P could not be measured separately. The amount of P found in the water either reflected the maximum concentration of PO_4^- or the maximum concentration of P_2O_5. For zone A and B the concentrations of P in the water exceeded the range and were therefore diluted (25times) before analysing.

The amount of K in the sewagewater samples was measured using the flame photometry method (Clesceri et al., 1998). Using this method, potassium is determined in a direct-reading type of flame photometer at a wavelength of 776.5 nm. The minimum level of K that can be detected is 0.1mg/l.

Measurements on Cl^-, pH and EC carried out to detect abnormal water (Ayers et al., 1985) and provide general information about the salt content of the water. Chloride was measured using analytical test strip, identifying the amount of Cl- ranging from 0-3000 mg/l, using a colour scale. The pH was measured through a simple pH meter instrument. The EC was measured through a conductivity meter.

B. Soil analyses

Soil samples of soils grown with the selected crops in the study areas were collected once and analysed on their nutrient content. Plan was to collect a soil samples within a short period. In reality, sampling took up a period of one month and a half. The most critical aspect of soil testing is obtaining a soil sample that is representative for the field. It was chosen to collect composite samples of whole fields and greenhouses. This way of sampling resulted in 'averages' soil test values instead of the description of spatial variability. This corresponded with the sewagewater and plant analyses, which also gave average test values. From selected fields, a number of soil sub samples (spits) were taken to make up one composite sample. The amount of sub samples taken depended on the size of the area. Normally one hectare should be covered with around 40 spits to make up one composite sample (Ryan et. al., 1996; Fageria et al., 1997; Havlin et al., 1999). In the research, from fields with an area below 10 dunum, 5 sub samples were taken, from fields with an area bigger than 10 dunum, 10 sub samples and from each greenhouse 2 samples. This reduction in the amount of spits taken was needed in order to save time and energy. Field were described on basis of mean values. Soil samples were taken following a zigzag or diagonal pattern through the field, according to literature (Ryan et al., 1996; Fageria et al., 1997; Havlin et al., 1999). At a sample spot, the ground was cleared from plant growth. An augur with an inside diameter of 0.10 m was used to take the samples. Samples were taken at a depth from 0-30 cm and from 30-60cm, the later to indicate leaching effect. At fields grown with trees, also samples from 60-90 cm were taken, because the rooting depth of trees is much bigger than of vegetables and fodder. When a sample was taken, it was put in a bowl, mixed and stored in a sealed bag. The number of the farm, the date, kind of crop and sample depth was written down on the bag. After collection, soil samples were spread on newspapers and air-dried for a minimum of 24 hours. When dry, soil samples were pounded by hand using a stone and sieved using a 2-mm sieve. All processed sub samples from one field were put together in a bowel and thoroughly mixed. Out of this two composite samples with a known volume were taken, using a cup with a volume of 255 ml. one composite sample functioned as a back-up sample, the other one as a laboratory sample, ready for analysing on N, P and K content.

In the laboratory the processed composite samples were analysed on mineral N (ammonium plus nitrate), extractable P and extractable K (extractable plus soluble).

The mineral N fraction of the soil samples was calculated by adding the nitrate-nitrogen and ammonium-nitrogen fractions which were determined using a continuous-flow analysis (CFA). The mineral N content of the soil, expressed in mg/kg dry matter was calculated by:

Mineral N (ppm) = N reading in extract (mg/l) x 50 / W

where:

ppm (parts per million = mg/kg)
50 / W = conversion factor (50 = total volume of extract (ml),
W weight of soil taken (g)).

The sodium bicarbonate procedure of Olsen et al., (1954) is used as an index of the availability of P in calcareous soils, where the solubility of calcium phosphate is increased because of the precipitation of Ca2+ as CaCO3. Standard phosphorus solutions were made for reading on spectrophotometer to prepare a standard curve. The absorbency of the soil samples solutions was read using a wavelength of 690 nm. The extractable P content of the soil, expressed in mg/kg dry soil was calculated using the following equation:

Extractable P(ppm) = P reading from spectrophotometer (mg/l) x 100 / 5 x 50 / 1 where:

100 / 5 = conversion factor (100 = total volume of extract (ml), 5 = weight of soil taken (g)).
50 / 1 = dilution factor.

C. Plant analyses

Plant samples from the selected fields were collected once during the whole research period. In the literature (Ryan et al., 1996; Fageria et al., 1997; Havlin et al., 1999) guidelines were found for plant sampling and analyses. These guidelines were used to identify nutrient deficiencies. In this research the nutrients removed through harvesting needed to be identified. Therefore, the crops were sampled at (or close to) harvest time, in order to know what left the fields.

The plants that needed to be sampled were selected randomly in the open field. For greenhouses the total number of plants needed to be sampled was divided by the number of greenhouses selected for the research, the out coming number of plants were sampled randomly in each greenhouses (i.e. greenhouses of cucumber 25/5 = 5, so 5 plants per greenhouse were sampled). The specified parts of the plant were removed from the crop using a clasp-knife and put together to make a composite sample. The samples were stored in paper bags, the number of the farm, the date, the crop and number of plants sampled was written on the bag. In the laboratory the samples were washed with distilled water, in order to remove dust, pesticide and fertilizer residue. The samples were air dried first and after this dried in oven at 65 ^{o}C for 24 hours to stop enzymatic activity. The dry samples were mechanically ground to produce a material suitable for analyses in a stainless steel mill.

In the laboratory the processed composite samples were analysed for total N, total P and total K.

The method used to determine the total N in the plant samples was based on digestion of the plant material in a sulfuric-salicyclic acid mixture (Ryan et al., 1996). After digestion the samples were distillated and titrated. The total N content of the plant (dry matter) was calculated using the following equation:

$$Total\ N\ (\%) = (V - B) \times A \times (14.01) \times R \times 100 / W \times 1000$$

where:

V = volume of acid needed to titrate distilled solutions (ml)
B = volume of acid titrated for blank (ml)
A = normality of acid
14.01 = atomic weight of nitrogen
R = ratio of digestion volume to distillation volume
W = dry plant weight (g)

The method of analysing the total P in the plant was based on digestion of plant material and measurement of P colorimetrically (Ryan et al., 1996). The absorbency of the plant sample was read using a wavelength of 410 nm and converted to mg/l. The total P content of the plant (dry matter), was calculated through the following equation:

Total P (%) = P reading from spectrophotometer (mg/l) x 100 / W x 50 / 1 x 0.0001

where:

100/W = conversion factor (100 = total volume of extract (ml), W = dry plant weight (g))
50 / 1 = dilution factor
0.0001 = conversion factor to go from ppm to %

K total in the plant sample was analysed by dry ashing. The concentrations of K in the resulted solutions were read by a flame photometer. The total K in the plant (dry matter) was calculated using the following equation:

Total K (%) = K reading from flame photometer (mg/l) x 50 / 0.5 x 100 / 1 x 0.0001

where:

50 / 0.5 = conversion factor (50 = total volume of extract (ml), 0.5 = dry plant weight (g))
100 / 1 = dilution factor
0.0001 = conversion factor to go from ppm to %

D. Theoretical water requirements of crops

The CROPWAT computer program for irrigation planning and management (Smith, 1992) was used to calculate the theoretical water requirement of the selected crops. The objective of these calculations was to give an indication of either insufficient or excess irrigation practices within the farming systems of the farms selected. General climate data of meteorological stations in Dier Alla (Middle Jordan Valley region) and Zarqa (Seil Al Zarqa region) were retrieved from the CROPWAT database and used within the calculations. These general data were considered satisfactory because irrigation scheduling within the different zones can be considered more or less independent from rainfall. Within zones A and B, crops are less irrigated during months with rainfall (January – March) but this is lined to the growth stage of the crops. Both alfalfa and apricot are dormant during winter months. In zone C crops are irrigated year-round because these are grown in greenhouses (where rainfall is not effective) and if grown at open fields, evapotranspiration is high during the whole year because of high temperatures and rainfall can be neglected.

Data used to calculate the theoretical water requirements of the selected crops are shown in table below. The choice of this input data was based on the following assumptions and arguments:

- the use of CROPWAR for calculating the water requirement of crops grown in greenhouses in dubious because the program is not including the specific conditions present in greenhouses.
- Because of the rainfall pattern and farmers' action on this (see above), effective rainfall in zone A and B was assumed to be 50% for zone C 1% (0% is not accepted in the model).
- No file for cucumber crop characteristics is present in CROPWAT, characteristics of small vegetable were used.
- Tomato and cucumber were considered are crops that once go through all growth stages during one growing season, alfalfa goes through all growth stages after each cutting of the crop and this information was inserted in CROPWAT by making a crop calendar of alfalfa.
- The planting date and length of the growing season used are averages of all selected farms.
- The irrigation efficiency for A1 65%, B2 70%, and for all farms in Jordan Valley 80%.
- Based on information from farm interviews and field observations it was calculated that application depth of irrigation within all zones lies around 70 mm.

Crop	**Retrieved files and data used**							
	Climate	Soil	Crop	Planting date	Length of growing season	Effective rainfall	Irrigation efficiency	Application depth
Alfalfa	Zarqa	Medium	Alfalfa 25	---	---	50%	65%	70mm
Apricot	Zarqa	Medium	Citrus	---	---	50%	60%	70mm
Tomato	Deir Alla	Medium	Tomato	1/11	191 days	1%	70%	70mm
Cucumber	Deir Alla	Medium	Small Veg.	1/11	161 days	1%	80%	70mm
Onion	Deir Alla	Medium	Onion	15/12	137 days	1%	80%	70mm
Potato	Deir Alla	Medium	Potato	28/11	98 days	1%	80%	70mm

All soils and irrigation waters contains a mixture of soluble salts, not all of which are essential for plant growth. The salt concentration of the soil solution is usually higher than that of the applied water. The increase in salinity results from plant transpiration and soil surface evaporation, which selectively remove water, concentrating the salts in the remaining soil water. To prevent soil salinity from reaching the harmful levels, it is necessary to remove a portion of the concentrated soil solution from the crop root zone by leaching (see paragraph 7.1.1). salts will be leached whenever water application exceeds evapotranspiration, providing that soil infiltration and drainage rates are adequate. The key to salinity control is a net downward movement of soil water in the root zone. How much leaching is required depends on the quality of the irrigation water, the crop grown, and the frequency and uniformity of irrigation. The minimum proportion of irrigation water supplied that must be drained through the root zone to control soil salinity in zones A, B and C can be seen at table 7.4 and these proportions were used in the research to control salinity problem.

Beside that, in Jordan Valley, the growing season starts with a period of land preparation, which includes leaching and fumigation. In earlier days, fumigation was performed with methyl bromide, but since methyl bromide is marked a one of the chemicals contributing to the depletion of the ozone-layer, its use has become more restricted. Nowadays the farmers in Jordan Valley were advised to use solar radiation in soil fumigation instead of methyl bromide. This is a method for controlling soil-borne pathogens and weeds, and is mostly done as a pre-planting soil treatment. The farm (greenhouses) is divided into basins with ridges high enough to prevent surface runoff. All the ridges and drip-lines are covered with plastic. The Jordan Valley Authority calculated that each greenhouse needs about 60 m^3 of water for soil fumigation and it is applied in two gifts. Due to the plastic the temperature rises to a level where all bacteria and viruses die-off. This could be also perceived as extra leaching at the same time. The evaporation from the soil surface is stopped since the plastic cover will prevent it, allowing all the water to infiltrate down to the root zone.

All farms have pumps that deliver water to the fields. The specification of the pumps, as the capacity (m^3/hour), is known that allow us to measure how much is delivered directly from stream as in zones A and B or from constructed ponds as in zone C. In Jordan Valley tensiometers were installed in the pilot farms to help us in calculating the irrigation frequency. It is advisable to irrigate more frequent, since increasing irrigation frequency increases the average soil water content. Particularly the upper portion of the root zone is maintained low in salinity if each irrigation is adequate. Frequent irrigations also permit small water applications that minimise surface run-off. Simply applying more water less frequent often will not be beneficial, because the extra water is lost to surface run-off or lowers application efficiency. For more details about water application in each pilot farm refer to Appendix 8.7 Water applied.

Appendix 8.7 Actual water applied compared to theoretical water applied calculated through CROPWAT

Farm	**Crop**	**Area**	**Irrigation system**	**Actual water applied**		**Calculated water requirement**			**Excess**	
		dunum		Volume (m3)	**Depth (mm)**	CWR (mm)	IE (%)	**IWR (mm)**	Depth (mm)	**Volume (m3)**
A1	Alfalfa	6.1	Surface (Border)	15936.3	**2612.5**	883	65	**1358**	1254	**7650**
B1	Alfalfa	30.5	Surface (Basin)	94550.0	**3100.0**	883	60	**1472**	1628	**49664**
B2	Apricot	14.4	Drip	746.2	**1360.0**	923	70	**1319**	41	**597**
C1	Cucumber	1.4	Drip	675.0	**482.1**	360	80	**450**	32	**45**
	Tomato	1.1	Drip	712.8	**648.0**	498	80	**623**	25	**28**
C2	Onion	3.8	Drip	2112.0	**555.8**	341	80	**426**	130	**492**
	Cucumber	2.2	Drip	972.0	**441.8**	360	80	**450**	-8	**-18**
C3	Potato	8.7	Drip	2320.0	**266.7**	179	80	**224**	43	**373**
	Tomato	4.5	Drip	2993.1	**665.1**	498	80	**623**	43	**192**

Appendix 8.7 Harvested plant portions nutrient content

Farm	**Crop**	**Measured area**	**Yield**		**Dry matter**	**Plant analysis**			**Harvest nutrient content**		
		dunum	kg/unit	total kg	%	% N dry matter	% P dry matter	% K dry matter	**N kg**	**P kg**	**K kg**
A1	Alfalfa	6.1	1300 kg/cut	150670	20	4.2	0.59	2.3	**1265.6**	**177.8**	**693.1**
B1	Alfalfa	30.5	1400 kg/cut	811300	20	4.5	0.63	2.2	**7301.7**	**1022.2**	**3569.7**
B2	Apricot	14.4 (182 tree)	28-33 kg/tree	5551	12	4.5	0.23	3.2	**30.0**	**1.5**	**21.3**
C1	Cucumber	1.4 (5 G.H)	9100 kg/G.H	47500	3.5	3.1	0.43	2.3	**51.5**	**7.1**	**38.2**
	Tomato	1.1 (4 G.H)	7000 kg/G.H	36000	5	4.9	0.51	3.8	**88.2**	**9.2**	**68.4**
C2	Onion	3.8	2500 kg/du	11400	14	3.3	0.31	3	**52.7**	**4.9**	**47.9**
	Cucumber	2.2 (5 G.H)	8100 kg/G.H	45000	3.5	3.4	0.4	2.3	**53.6**	**6.3**	**36.2**
C4	Potato	8.7	3700 kg/du	34800	20	3.5	0.2	2.6	**243.6**	**13.9**	**181.0**
	Tomato	4.5 (10 G.H)	7500 kg/G.H	85000	5	3.6	0.53	4.4	**153.0**	**22.5**	**187.0**

Appendix 8.7 Amount of N, P, and K in plants in % dry matter

Farm	**Crop**	**Measured area**	**Plant analysis**		
		dunum	**% N dry matter**	**% P dry matter**	**% K dry matter**
A1	Alfalfa	6.1	**4.2**	**0.59**	**2.3**
B1	Alfalfa	30.5	**4.5**	**0.63**	**2.2**
B2	Apricot	14.4 (182 tree)	**4.5**	**0.23**	**3.2**
C1	Cucumber	1.4 (5 G.H)	**3.1**	**0.43**	**2.3**
	Tomato	1.1 (4 G.H)	**4.9**	**0.51**	**3.8**
C2	Onion	3.8	**3.3**	**0.31**	**3**
	Cucumber	2.2 (5 G.H)	**3.4**	**0.4**	**2.3**
C4	Potato	8.7	**3.5**	**0.2**	**2.6**
	Tomato	4.5 (10 G.H)	**3.6**	**0.53**	**4.4**

Appendix 8.7 Soil weight over sampling depth

Farm	Crop	Measured area	Depth	Volume soil	Type of soil	Bulk density		Weight soil	
		dunum	cm	m3		g/ml	kg/m3	kg	**ton**
A1	Alfalfa	6.1	00-30	1830	silty clay	1.3	1300	2379000	**2379.0**
			30-60	1830				2379000	**2379.0**
B1	Alfalfa	30.5	00-30	9150	silty clay	1.3	1300	11895000	**11895.0**
			30-60	9150				11895000	**11895.0**
B2	Apricot	14.4	00-30	4320	silty clay	1.3	1300	5616000	**5616.0**
			30-60	4320				5616000	**5616.0**
			60-90	4320				5616000	**5616.0**
C1	Cucumber	1.4	00-30	330	clay	1.25	1250	412500	**412.5**
			30-60	330				412500	**412.5**
	Tomato	1.1	00-30	420				525000	**525.0**
			30-60	420				525000	**525.0**
C2	Onion	3.8	00-30	1140	clay loam	1.35	1350	1539000	**1539.0**
			30-60	1140				1539000	**1539.0**
	Cucumber	2.2	00-30	660				891000	**891.0**
			30-60	660				891000	**891.0**
C3	Potato	4.5	00-30	1350	clay	1.25	1250	1687500	**1687.5**
			30-60	1350				1687500	**1687.5**
	Tomato	8.7	00-30	2610				3262500	**3262.5**
			30-60	2610				3262500	**3262.5**

Appendix 8.7 Amount of N, P, and K in soil layers in ppm of dry soil

Farm	**Crop**	**Depth** cm	**N mineral** ppm	**P extractable** ppm	**K extractable** ppm
A1	Alfalfa	00-30	**32.3**	**102**	**320**
		30-60			
B1	Alfalfa	00-30	**39.3**	**75**	**300**
		30-60	**28.9**	**15**	**200**
B2	Apricot	00-30	**73.3**	**61**	**350**
		30-60	**37.2**	**47**	**180**
		60-90	**7.6**	**35**	**100**
C1	Cucumber	00-30	**71.4**	**157**	**300**
		30-60	**27.5**	**37**	**210**
	Tomato	00-30	**9.2**	**162**	**320**
		30-60	**23.6**	**49**	**190**
C2	Onion	00-30	**12.0**	**65**	**170**
		30-60	**3.9**	**21**	**110**
	Cucumber	00-30	**11.3**	**113**	**220**
		30-60	**8.6**	**67**	**170**
C3	Potato	00-30	**15.1**	**72**	**430**
		30-60	**14.8**	**22**	**250**
	Tomato	00-30	**61.5**	**88**	**480**
		30-60	**38.5**	**24**	**270**

Appendix 8.7 Soil nutrient content

Farm	**Crop**	**Measured area**	**Depth**	**Weight soil**	**Soil analysis**			**Soil nutrient content**					
		dunum	cm	ton	N	P	K	**N**		**P**		**K**	
					mg/kg	mg/kg	mg/kg	kg	**kg/ha**	kg	**kg/ha**	kg	**kg/ha**
A1	Alfalfa	6.1	00-30	1830	32.3	102	320	59.1	**96.9**	187.1	**306.7**	585.6	**960**
			30-60	1830									
B1	Alfalfa	30.5	00-30	9150	39.3	75	300	359.6	**117.9**	689.0	**225.9**	2743.8	**900**
		30.5	30-60	9150	28.9	15	200	264.4	**86.7**	134.1	**44.0**	1830.0	**600**
B2	Apricot	14.4	00-30	5616	73.3	61	350	411.7	**285.9**	341.8	**237.4**	1965.6	**1365**
		14.4	30-60	5616	37.2	47	180	208.9	**145.1**	266.7	**185.2**	1010.9	**702**
		14.4	60-90	5616	7.6	35	100	42.7	**29.6**	195.3	**135.6**	561.6	**390**
C1	Cucumber	1.4	00-30	412.5	71.4	157	300	29.4	**210.3**	64.8	**462.6**	123.8	**884**
		1.4	30-60	412.5	27.5	37	210	11.4	**81.1**	15.1	**107.8**	86.6	**619**
	Tomato	1.1	00-30	525	9.2	162	320	4.8	**43.9**	85.1	**773.2**	168.0	**1527**
		1.1	30-60	525	23.6	49	190	12.4	**112.5**	25.9	**235.2**	99.8	**907**
C2	Onion	3.8	00-30	1539	12.0	65	170	18.5	**48.7**	100.0	**263.3**	261.6	**689**
		3.8	30-60	1539	3.9	21	110	6.0	**15.7**	32.3	**85.1**	169.3	**446**
	Cucumber	2.2	00-30	891	11.3	113	220	10.0	**45.6**	100.5	**457.0**	196.0	**891**
		2.2	30-60	891	8.6	67	170	7.6	**34.6**	59.7	**271.5**	151.5	**689**
C4	Potato	4.5	00-30	1687.5	15.1	72	430	25.5	**56.6**	121.5	**270.0**	725.6	**1613**
		4.5	30-60	1687.5	14.8	22	250	25.0	**55.5**	37.1	**82.5**	421.9	**938**
	Tomato	8.7	00-30	3262.5	61.5	88	480	200.6	**230.6**	286.0	**328.7**	1566.0	**1800**
		8.7	30-60	3262.5	38.5	24	270	125.6	**144.4**	79.2	**91.1**	880.9	**1013**

Appendix 8.7 Water applied

Farm	**Crop**	**Area**		**Water application**								
		Total Dunum	**Measured Dunum**	Period season	Interval times/days	Turns number	Duration hrs/area	Laterals length (m)	Emitters number	Discharge l/hr	Amount l	**Total m3**
A1	Alfalfa	13.2	**6.1**	winter	1/14	13	50 min/du	13.2 du/11hrs		95 m3/hr	6277.917	**15936.3**
				summer	1/8	20	50 min/du	13.2 du/11hrs		95 m3/hr	9658.333	
B1	Alfalfa	45	**30.5**	Apr.-Dec.	1/8-9	31	50min/du	45 du/45 hrs		120 m3/hr	94550	**94550.0**
B2	Apricot	14.5	**14.4(182 tree)**	Feb.-Sep.	1/3	82	1/tree	182 tree		50	746200	**746.2**
C1	Cucumber	3.1	**1.4(5G.H)**	overponding	1	1	12/G.H	180/G.H	450/G.H	4	108000	**675.0**
				winter	1/7	14	1.5/G.H	180/G.H	450/G.H	4	189000	
				summer	1/3	21	2/G.H	180/G.H	450/G.H	4	378000	
	Tomato	1.1	**1.1(4G.H)**	overponding	1	1	12/G.H	180/G.H	450/G.H	4	86400	**712.8**
				winter	1/4-5	18	1.5/G.H	180/G.H	450/G.H	4	194400	
				summer	1/3	30	2/G.H	180/G.H	450/G.H	4	432000	
C2	Onion	10.7	**3.8(1 plot)**	winter	1/7	15	1/plot	4800/plot	16000/plot	4	960000	**2112.0**
				summer	2/7	18	1/plot	4800/plot	16000/plot	4	1152000	
	Cucumber	4.4	**2.2(5G.H)**	overponding	1	1	12/G.H	270/G.H	900/G.H	4	216000	**972.0**
				winter	1/7	12	1.5/G.H	270/G.H	900/G.H	4	324000	
				summer	1/3	28	2/G.H	270/G.H	900/G.H	4	432000	
C3	Potato	8.7	**8.7(1 plot)**	pre-irrigation	1	1	1/plot	5800/plot	29000/plot	4	116000	**2320.0**
				growing season	1/5	19	1/plot	5800/plot	29000/plot	4	2204000	
	Tomato	11.3	**4.5(10G.H)**	overponding	1	1	12/G.H	287.8/G.H	1439/G.H	4	690720	**2993.1**
				winter	1/7	10	1/G.H	287.8/G.H	1439/G.H	4	575600	
				summer	1/3	40	45min/G.H	287.8/G.H	1439/G.H	4	1726800	

Annex 8.7 Fertilisers applied

Farm	Crop	Area				Fertilisers application						
		Total Dunum	Selected Dunum	Unit	Total Units	Kind	Type %N:%P:%K	Frequency Times	Amount kg/unit	Total		
										N (kg)	**P (kg)**	**K (kg)**
A1	Alfalfa	13.2	6.1	plot	2	non	non	non	non	non	non	non
B1	Alfalfa	45	30.5	plot	2	non	non	non	non	non	non	non
B2	Apricot	14.4	14.4	tree	182	Urea	46:00:00	1	0.25	21	0	0
				dunum		NPK	0:00:26	2	4	0	0	30
									Total	**21**	**0**	**30**
C1	Cucumber	3.1	1.4	G.H	5	NPK	20:20:20	7	2	14	6.1	11.6
						NPK	0:36:00	2	2	0	3.15	0
						NPK	0:00:38	1	2	0	0	3.15
									Total	**14**	**9.3**	**14.77**
	Tomato	1.1	1.1	G.H	4	NPK	20:20:20	7	2	11.2	4.89	9.3
						NPK	0:36:00	2	2	0	2.5	0
						NPK	0:00:38	4	2	0	0	10.1
									Total	**11.2**	**7.39**	**19.4**
C2	Onion	10.7	3.8	dunum	3.8	Ammoniac	30:00:00	2	30	18	0	0
						Urea	46:00:00	2	15	13.8	0	0
				whole field		NPK	12:00:46	2	50	12	0	38.18
									Total	**43.8**	**0**	**38.18**
	Cucumber	4.4	2.2	G.H	5	NPK	20:10:10	2	2	4	0.874	1.66
						NPK	20:20:20	12	2	24	10.49	19.92
									Total	**28**	**11.36**	**21.58**
C3	Potato	8.7	8.7	dunum	8.7	DAP	18:48:00	1	15	23.49	27.37	0
						NPK	22:00:00	4	10	76.56	0	0
						NPK	13:00:46	2	5	11.31	0	33.22
									Total	**100.05**	**27.37**	**33.22**
	Tomato	11.3	4.5	G.H	10	NPK	22:00:00	3	2	13.2	0	0
						NPK	15.5:0:0	4	2	12.4	0	0
						NPK	20:20:20	3	2	12	5.28	9.96
						NPK	18:06:26	15	3	81	11.8	97.11
						NPK	17:06:18	3	2	10.2	1.57	8.96
						NPK	10:11:13	6	2	12	5.77	12.95
						NPK	10:12:14	8	2	16	8.39	18.59
									Total	**156.8**	**32.81**	**147.57**

Appendix 8.7 Manure applied

Farm	**Crop**	**Area**				**Manure application**					
		Total Dunum	Selected Dunum	Unit	Total Units	Kind	Frequency Times	Amount kg/unit	**Total**		
									N (kg)	**P (kg)**	**K (kg)**
A1	Alfalfa	13.2	6.1	dunum	6.1	goat/sheep	1	250	**26.7**	**10**	**38**
B1	Alfalfa	45	30.5	plot	2	non	non	non	**non**	**non**	**non**
B2	Apricot	14.4	14.4	tree	182	cow	1	30	**54.7**	**17.9**	**45.2**
C1	Cucumber	3.1	1.4	G.H	5	goat	1	1000	**75**	**33**	**125**
	Tomato	1.1	1.1	G.H	4	goat/poultry	1	1000	**130**	**39.2**	**75.2**
C3	Onion	10.7	3.8	dunum	1	cow/sheep	1	500	**27.1**	**8.9**	**28.2**
	Cucumber	4.4	2.2	G.H	5	goat	1	1000	**75**	**33**	**125**
C4	Potato	8.7	8.7	whole area	8.7	cow/sheep	1	4350	**87**	**28.4**	**90.5**
	Tomato	11.3	4.5	G.H	10	goat	1	1000	**150**	**65.1**	**250**

Appendix 8.7 Nutrient supply through water, fertiliser, and manure

Farm	**Crop**	**Area**	**Water**	**Nutrients**			**N supply**				**P supply**				**K supply**			
		dunum	**application**	N	P	K	water	fertiliser	manure	**Total**	water	fertiliser	manure	**Total**	water	fertiliser	manure	**Total**
			m3	g/m3	g/m3	g/m3	Kg	Kg	Kg	**Kg**	Kg	Kg	Kg	**Kg**	Kg	Kg	Kg	**Kg**
A1	Alfalfa	6.1	15936.3	90.0	19.0	41.8	1434.3	0.0	26.7	**1461.0**	302.8	0.0	10.0	**312.8**	666.1	0.0	38.0	**704.1**
B1	Alfalfa	30.5	94550.0	85.0	19.0	39.1	8036.8	0.0	0.0	**8036.8**	1796.5	0.0	0.0	**1796.5**	3696.9	0.0	0.0	**3696.9**
B2	Apricot	14.4	746.2	66.0	19.0	37.9	49.2	21.0	54.7	**124.9**	14.2	0.0	17.9	**32.1**	28.3	30.0	45.2	**103.5**
C1	Cucumber	1.4	675.0	27.5	5.3	38.1	18.6	14.0	75.0	**107.6**	3.6	9.3	33.0	**45.9**	25.7	14.8	125.0	**165.5**
	Tomato	1.1	712.8	27.5	5.3	38.1	19.6	11.2	130.0	**160.8**	3.8	7.4	39.2	**50.4**	27.2	19.4	75.2	**121.8**
C2	Onion	3.8	2112.0	32.0	7.1	37.0	67.6	43.8	27.1	**138.5**	15.0	0.0	8.9	**23.9**	78.1	38.2	28.2	**144.5**
	Cucumber	2.2	972.0	32.0	7.1	37.0	31.1	28.0	75.0	**134.1**	6.9	11.4	33.0	**51.3**	36.0	21.6	125.0	**182.6**
C3	Potato	8.7	2320.0	28.9	6.1	33.2	67.0	100.1	87.0	**254.1**	14.2	27.4	28.4	**70.0**	77.0	33.2	90.5	**200.7**
	Tomato	4.5	2993.1	28.9	6.1	33.2	86.5	156.8	150.0	**393.3**	18.3	32.8	65.1	**116.2**	99.4	147.6	250.0	**497.0**

Appendix 8.7

Nitrogen mass balance

Farm	**Crop**	**Measured area**	**N inflow**					**N outflow**		**N storage**
		dunum	water	fertiliser	manure	**Total**		**Harvest**		
			Kg	Kg	Kg	Kg	**kg/ha**	kg	**kg/ha**	**kg/ha**
A1	Alfalfa	6.1	1434.3	0.0	26.7	1461.0	**2395.1**	1265.6	**2074.8**	**320.3**
B1	Alfalfa	30.5	8036.8	0.0	0.0	8036.8	**2635.0**	7301.7	**2394.0**	**241.0**
B2	Apricot	14.4	49.2	21.0	54.7	124.9	**86.7**	30.0	**20.8**	**65.9**
C1	Cucumber	1.4	18.6	20.0	75.0	113.6	**811.4**	51.5	**367.9**	**443.6**
	Tomato	1.1	19.6	16.0	130.0	165.6	**1505.5**	88.2	**801.8**	**703.6**
C2	Onion	3.8	67.6	43.8	27.1	138.5	**364.5**	52.7	**138.7**	**225.8**
	Cucumber	2.2	31.1	28.0	75.0	134.1	**609.5**	53.6	**243.6**	**365.9**
C4	Potato	8.7	67.0	234.0	87.0	388.0	**446.0**	243.6	**280.0**	**166.0**
	Tomato	4.5	86.5	188.2	150.0	424.7	**943.8**	153.0	**340.0**	**603.8**

Phosphorus mass balance

Farm	**Crop**	**Measured area**	**P inflow**					**P outflow**		**P storage**
		dunum	water	fertiliser	manure	**Total**		**Harvest**		
			Kg	Kg	Kg	Kg	**kg/ha**	kg	**kg/ha**	**kg/ha**
A1	Alfalfa	6.1	302.8	0.0	10.0	312.8	**512.8**	177.8	**291.5**	**221.3**
B1	Alfalfa	30.5	1796.5	0.0	0.0	1796.5	**589.0**	1022.2	**335.1**	**253.9**
B2	Apricot	14.4	14.2	0.0	17.9	32.1	**22.3**	1.5	**1.0**	**21.3**
C1	Cucumber	1.4	3.6	12.0	33.0	48.6	**347.1**	7.1	**50.7**	**296.4**
	Tomato	1.1	3.8	9.5	39.2	52.5	**477.3**	9.2	**83.6**	**393.6**
C2	Onion	3.8	15.0	0.0	8.9	23.9	**62.9**	4.9	**12.9**	**50.0**
	Cucumber	2.2	6.9	11.4	33.0	51.3	**233.2**	6.3	**28.6**	**204.5**
C3	Potato	8.7	14.2	36.5	28.4	79.1	**90.9**	13.9	**16.0**	**74.9**
	Tomato	4.5	18.3	36.7	65.1	120.1	**266.9**	22.5	**50.0**	**216.9**

Potassium mass balance

Farm	**Crop**	**Measured area**	**K inflow**					**K outflow**		**K storage**
		dunum	water	fertiliser	manure	**Total**		**Harvest**		
			Kg	Kg	Kg	Kg	**kg/ha**	kg	**kg/ha**	**kg/ha**
A1	Alfalfa	6.1	666.1	0.0	38.0	704.1	**1154.3**	693.1	**1136.2**	**18.0**
B1	Alfalfa	30.5	3696.9	0.0	0.0	3696.9	**1212.1**	3569.7	**1170.4**	**41.7**
B2	Apricot	14.4	28.3	30.0	45.2	103.5	**71.9**	21.3	**14.8**	**57.1**
C1	Cucumber	1.4	25.7	19.8	125.0	170.5	**1217.9**	38.2	**272.9**	**945.0**
	Tomato	1.1	27.2	28.4	75.2	130.8	**1189.1**	68.4	**621.8**	**567.3**
C2	Onion	3.8	78.1	38.2	28.2	144.5	**380.3**	47.9	**126.1**	**254.2**
	Cucumber	2.2	36.0	21.6	125.0	182.6	**830.0**	36.2	**164.5**	**665.5**
C3	Potato	8.7	77.0	33.2	90.5	200.7	**230.7**	181.0	**208.0**	**22.6**
	Tomato	4.5	99.4	179.9	250.0	529.3	**1176.2**	187.0	**415.6**	**760.7**

Appendix 8.7 Treated sewage water as a crop nutrient source, expressed in percentage

Farm	**Crop**	**Area**	**Treated sewage water as nutrient source**		
		dunum	Harvested outflow		
			% N	**% P**	**% K**
A1	Alfalfa	6.1	**113.3**	**170.3**	**96.1**
B1	Alfalfa	30.5	**110.1**	**175.8**	**103.6**
B2	Apricot	14.4	**164**	**946.7**	**132.9**
C1	Cucumber	1.4	**37.7**	**15.8**	**70.2**
	Tomato	1.1	**28.6**	**53.5**	**51.1**
C2	Onion	3.8	**154**	**365.9**	**195.7**
	Cucumber	2.2	**64.5**	**121.1**	**110.4**
C3	Potato	8.7	**29.7**	**110.1**	**46**
	Tomato	4.5	**64.1**	**92**	**60.2**

Appendix 8.7 Actual water applied compared to theoretical water applied calculated through CROPWAT

Farm	**Crop**	**Area**	**Irrigation system**	**Actual water applied**		**Calculated water requirement**			**Excess**	
		dunum		Volume (m3)	**Depth (mm)**	CWR (mm)	IE (%)	**IWR (mm)**	Depth (mm)	**Volume (m3)**
A1	Alfalfa	6.1	Surface (Border)	15936.3	**2612.5**	883	65	**1358**	1254	**7650**
B1	Alfalfa	30.5	Surface (Basin)	94550.0	**3100.0**	883	60	**1472**	1628	**49664**
B2	Apricot	14.4	Drip	746.2	**1360.0**	923	70	**1319**	41	**597**
C1	Cucumber	1.4	Drip	675.0	**482.1**	360	80	**450**	32	**45**
	Tomato	1.1	Drip	712.8	**648.0**	498	80	**623**	25	**28**
C2	Onion	3.8	Drip	2112.0	**555.8**	341	80	**426**	130	**492**
	Cucumber	2.2	Drip	972.0	**441.8**	360	80	**450**	-8	**-18**
C3	Potato	8.7	Drip	2320.0	**266.7**	179	80	**224**	43	**373**
	Tomato	4.5	Drip	2993.1	**665.1**	498	80	**623**	43	**192**

Appendix 8.7 Harvested plant portions nutrient content

Farm	**Crop**	**Measured area**	**Yield**		**Dry matter**	**Plant analysis**			**Harvest nutrient content**		
		dunum	kg/unit	total kg	%	% N dry matter	% P dry matter	% K dry matter	**N kg**	**P kg**	**K kg**
A1	Alfalfa	6.1	1300 kg/cut	150670	20	4.2	0.59	2.3	**1265.6**	**177.8**	**693.1**
B1	Alfalfa	30.5	1400 kg/cut	811300	20	4.5	0.63	2.2	**7301.7**	**1022.2**	**3569.7**
B2	Apricot	14.4 (182 tree)	28-33 kg/tree	5551	12	4.5	0.23	3.2	**30.0**	**1.5**	**21.3**
C1	Cucumber	1.4 (5 G.H)	9100 kg/G.H	47500	3.5	3.1	0.43	2.3	**51.5**	**7.1**	**38.2**
	Tomato	1.1 (4 G.H)	7000 kg/G.H	36000	5	4.9	0.51	3.8	**88.2**	**9.2**	**68.4**
C2	Onion	3.8	2500 kg/du	11400	14	3.3	0.31	3	**52.7**	**4.9**	**47.9**
	Cucumber	2.2 (5 G.H)	8100 kg/G.H	45000	3.5	3.4	0.4	2.3	**53.6**	**6.3**	**36.2**
C4	Potato	8.7	3700 kg/du	34800	20	3.5	0.2	2.6	**243.6**	**13.9**	**181.0**
	Tomato	4.5 (10 G.H)	7500 kg/G.H	85000	5	3.6	0.53	4.4	**153.0**	**22.5**	**187.0**

Appendix 8.7 Amount of N, P, and K in plants in % dry matter

Farm	**Crop**	**Measured area**	**Plant analysis**		
		dunum	**% N dry matter**	**% P dry matter**	**% K dry matter**
A1	Alfalfa	6.1	**4.2**	**0.59**	**2.3**
B1	Alfalfa	30.5	**4.5**	**0.63**	**2.2**
B2	Apricot	14.4 (182 tree)	**4.5**	**0.23**	**3.2**
C1	Cucumber	1.4 (5 G.H)	**3.1**	**0.43**	**2.3**
	Tomato	1.1 (4 G.H)	**4.9**	**0.51**	**3.8**
C2	Onion	3.8	**3.3**	**0.31**	**3**
	Cucumber	2.2 (5 G.H)	**3.4**	**0.4**	**2.3**
C4	Potato	8.7	**3.5**	**0.2**	**2.6**
	Tomato	4.5 (10 G.H)	**3.6**	**0.53**	**4.4**

Appendix 8.7 Soil weight over sampling depth

Farm	Crop	Measured area	Depth	Volume soil	Type of soil	Bulk density		Weight soil	
		dunum	cm	m3		g/ml	kg/m3	kg	**ton**
A1	Alfalfa	6.1	00-30	1830	silty clay	1.3	1300	2379000	**2379.0**
			30-60	1830				2379000	**2379.0**
B1	Alfalfa	30.5	00-30	9150	silty clay	1.3	1300	11895000	**11895.0**
			30-60	9150				11895000	**11895.0**
B2	Apricot	14.4	00-30	4320	silty clay	1.3	1300	5616000	**5616.0**
			30-60	4320				5616000	**5616.0**
			60-90	4320				5616000	**5616.0**
C1	Cucumber	1.4	00-30	330	clay	1.25	1250	412500	**412.5**
			30-60	330				412500	**412.5**
	Tomato	1.1	00-30	420				525000	**525.0**
			30-60	420				525000	**525.0**
C2	Onion	3.8	00-30	1140	clay loam	1.35	1350	1539000	**1539.0**
			30-60	1140				1539000	**1539.0**
	Cucumber	2.2	00-30	660				891000	**891.0**
			30-60	660				891000	**891.0**
C3	Potato	4.5	00-30	1350	clay	1.25	1250	1687500	**1687.5**
			30-60	1350				1687500	**1687.5**
	Tomato	8.7	00-30	2610				3262500	**3262.5**
			30-60	2610				3262500	**3262.5**

Appendix 8.7 Amount of N, P, and K in soil layers in ppm of dry soil

Farm	**Crop**	**Depth** cm	**N mineral** ppm	**P extractable** ppm	**K extractable** ppm
A1	Alfalfa	00-30	**32.3**	**102**	**320**
		30-60			
B1	Alfalfa	00-30	**39.3**	**75**	**300**
		30-60	**28.9**	**15**	**200**
B2	Apricot	00-30	**73.3**	**61**	**350**
		30-60	**37.2**	**47**	**180**
		60-90	**7.6**	**35**	**100**
C1	Cucumber	00-30	**71.4**	**157**	**300**
		30-60	**27.5**	**37**	**210**
	Tomato	00-30	**9.2**	**162**	**320**
		30-60	**23.6**	**49**	**190**
C2	Onion	00-30	**12.0**	**65**	**170**
		30-60	**3.9**	**21**	**110**
	Cucumber	00-30	**11.3**	**113**	**220**
		30-60	**8.6**	**67**	**170**
C3	Potato	00-30	**15.1**	**72**	**430**
		30-60	**14.8**	**22**	**250**
	Tomato	00-30	**61.5**	**88**	**480**
		30-60	**38.5**	**24**	**270**

Appendix 8.7 Soil nutrient content

Farm	**Crop**	**Measured area**	**Depth**	**Weight soil**	**Soil analysis**			**Soil nutrient content**					
		dunum	cm	ton	N	P	K	**N**		**P**		**K**	
					mg/kg	mg/kg	mg/kg	kg	**kg/ha**	kg	**kg/ha**	kg	**kg/ha**
A1	Alfalfa	6.1	00-30	1830	32.3	102	320	59.1	**96.9**	187.1	**306.7**	585.6	**960**
			30-60	1830									
B1	Alfalfa	30.5	00-30	9150	39.3	75	300	359.6	**117.9**	689.0	**225.9**	2743.8	**900**
		30.5	30-60	9150	28.9	15	200	264.4	**86.7**	134.1	**44.0**	1830.0	**600**
B2	Apricot	14.4	00-30	5616	73.3	61	350	411.7	**285.9**	341.8	**237.4**	1965.6	**1365**
		14.4	30-60	5616	37.2	47	180	208.9	**145.1**	266.7	**185.2**	1010.9	**702**
		14.4	60-90	5616	7.6	35	100	42.7	**29.6**	195.3	**135.6**	561.6	**390**
C1	Cucumber	1.4	00-30	412.5	71.4	157	300	29.4	**210.3**	64.8	**462.6**	123.8	**884**
		1.4	30-60	412.5	27.5	37	210	11.4	**81.1**	15.1	**107.8**	86.6	**619**
	Tomato	1.1	00-30	525	9.2	162	320	4.8	**43.9**	85.1	**773.2**	168.0	**1527**
		1.1	30-60	525	23.6	49	190	12.4	**112.5**	25.9	**235.2**	99.8	**907**
C2	Onion	3.8	00-30	1539	12.0	65	170	18.5	**48.7**	100.0	**263.3**	261.6	**689**
		3.8	30-60	1539	3.9	21	110	6.0	**15.7**	32.3	**85.1**	169.3	**446**
	Cucumber	2.2	00-30	891	11.3	113	220	10.0	**45.6**	100.5	**457.0**	196.0	**891**
		2.2	30-60	891	8.6	67	170	7.6	**34.6**	59.7	**271.5**	151.5	**689**
C4	Potato	4.5	00-30	1687.5	15.1	72	430	25.5	**56.6**	121.5	**270.0**	725.6	**1613**
		4.5	30-60	1687.5	14.8	22	250	25.0	**55.5**	37.1	**82.5**	421.9	**938**
	Tomato	8.7	00-30	3262.5	61.5	88	480	200.6	**230.6**	286.0	**328.7**	1566.0	**1800**
		8.7	30-60	3262.5	38.5	24	270	125.6	**144.4**	79.2	**91.1**	880.9	**1013**

Appendix 8.7 Water applied

Farm	**Crop**	**Area**		**Water application**								
		Total Dunum	**Measured Dunum**	Period season	Interval times/days	Turns number	Duration hrs/area	Laterals length (m)	Emitters number	Discharge l/hr	Amount l	**Total m3**
A1	Alfalfa	13.2	**6.1**	winter	1/14	13	50 min/du	13.2 du/11hrs		95 m3/hr	6277.917	**15936.3**
				summer	1/8	20	50 min/du	13.2 du/11hrs		95 m3/hr	9658.333	
B1	Alfalfa	45	**30.5**	Apr.-Dec.	1/8-9	31	50min/du	45 du/45 hrs		120 m3/hr	94550	**94550.0**
B2	Apricot	14.5	**14.4(182 tree)**	Feb.-Sep.	1/3	82	1/tree	182 tree		50	746200	**746.2**
C1	Cucumber	3.1	**1.4(5G.H)**	overponding	1	1	12/G.H	180/G.H	450/G.H	4	108000	**675.0**
				winter	1/7	14	1.5/G.H	180/G.H	450/G.H	4	189000	
				summer	1/3	21	2/G.H	180/G.H	450/G.H	4	378000	
	Tomato	1.1	**1.1(4G.H)**	overponding	1	1	12/G.H	180/G.H	450/G.H	4	86400	**712.8**
				winter	1/4-5	18	1.5/G.H	180/G.H	450/G.H	4	194400	
				summer	1/3	30	2/G.H	180/G.H	450/G.H	4	432000	
C2	Onion	10.7	**3.8(1 plot)**	winter	1/7	15	1/plot	4800/plot	16000/plot	4	960000	**2112.0**
				summer	2/7	18	1/plot	4800/plot	16000/plot	4	1152000	
	Cucumber	4.4	**2.2(5G.H)**	overponding	1	1	12/G.H	270/G.H	900/G.H	4	216000	**972.0**
				winter	1/7	12	1.5/G.H	270/G.H	900/G.H	4	324000	
				summer	1/3	28	2/G.H	270/G.H	900/G.H	4	432000	
C3	Potato	8.7	**8.7(1 plot)**	pre-irrigation	1	1	1/plot	5800/plot	29000/plot	4	116000	**2320.0**
				growing season	1/5	19	1/plot	5800/plot	29000/plot	4	2204000	
	Tomato	11.3	**4.5(10G.H)**	overponding	1	1	12/G.H	287.8/G.H	1439/G.H	4	690720	**2993.1**
				winter	1/7	10	1/G.H	287.8/G.H	1439/G.H	4	575600	
				summer	1/3	40	45min/G.H	287.8/G.H	1439/G.H	4	1726800	

Appendix 8.7 Fertilisers applied

Farm	**Crop**	**Area**				**Fertilisers application**						
		Total Dunum	Selected Dunum	Unit	Total Units	Kind	Type %N:%P:%K	Frequency Times	Amount kg/unit	**Total**		
										N (kg)	**P (kg)**	**K (kg)**
A1	Alfalfa	13.2	6.1	plot	2	non	non	non	non	non	non	non
B1	Alfalfa	45	30.5	plot	2	non	non	non	non	non	non	non
B2	Apricot	14.4	14.4	tree	182	Urea	46:00:00	1	0.25	21	0	0
				dunum		NPK	0:00:26	2	4	0	0	30
									Total	**21**	**0**	**30**
C1	Cucumber	3.1	1.4	G.H	5	NPK	20:20:20	7	2	14	6.1	11.6
						NPK	0:36:00	2	2	0	3.15	0
						NPK	0:00:38	1	2	0	0	3.15
									Total	**14**	**9.3**	**14.77**
	Tomato	1.1	1.1	G.H	4	NPK	20:20:20	7	2	11.2	4.89	9.3
						NPK	0:36:00	2	2	0	2.5	0
						NPK	0:00:38	4	2	0	0	10.1
									Total	**11.2**	**7.39**	**19.4**
C2	Onion	10.7	3.8	dunum	3.8	Ammoniac	30:00:00	2	30	18	0	0
						Urea	46:00:00	2	15	13.8	0	0
				whole field		NPK	12:00:46	2	50	12	0	38.18
									Total	**43.8**	**0**	**38.18**
	Cucumber	4.4	2.2	G.H	5	NPK	20:10:10	2	2	4	0.874	1.66
						NPK	20:20:20	12	2	24	10.49	19.92
									Total	**28**	**11.36**	**21.58**
C3	Potato	8.7	8.7	dunum	8.7	DAP	18:48:00	1	15	23.49	27.37	0
						NPK	22:00:00	4	10	76.56	0	0
						NPK	13:00:46	2	5	11.31	0	33.22
									Total	**100.05**	**27.37**	**33.22**
	Tomato	11.3	4.5	G.H	10	NPK	22:00:00	3	2	13.2	0	0
						NPK	15.5:0:0	4	2	12.4	0	0
						NPK	20:20:20	3	2	12	5.28	9.96
						NPK	18:06:26	15	3	81	11.8	97.11
						NPK	17:06:18	3	2	10.2	1.57	8.96
						NPK	10:11:13	6	2	12	5.77	12.95
						NPK	10:12:14	8	2	16	8.39	18.59
									Total	**156.8**	**32.81**	**147.57**

Apendix 8.7 Manure applied

Farm	Crop	Area				Manure application					
		Total Dunum	Selected Dunum	Unit	Total Units	Kind	Frequency Times	Amount kg/unit	**Total**		
									N (kg)	**P (kg)**	**K (kg)**
A1	Alfalfa	13.2	6.1	dunum	6.1	goat/sheep	1	250	**26.7**	**10**	**38**
B1	Alfalfa	45	30.5	plot	2	non	non	non	**non**	**non**	**non**
B2	Apricot	14.4	14.4	tree	182	cow	1	30	**54.7**	**17.9**	**45.2**
C1	Cucumber	3.1	1.4	G.H	5	goat	1	1000	**75**	**33**	**125**
	Tomato	1.1	1.1	G.H	4	goat/poultry	1	1000	**130**	**39.2**	**75.2**
C3	Onion	10.7	3.8	dunum	1	cow/sheep	1	500	**27.1**	**8.9**	**28.2**
	Cucumber	4.4	2.2	G.H	5	goat	1	1000	**75**	**33**	**125**
C4	Potato	8.7	8.7	whole area	8.7	cow/sheep	1	4350	**87**	**28.4**	**90.5**
	Tomato	11.3	4.5	G.H	10	goat	1	1000	**150**	**65.1**	**250**

Appendix 8.7 Nutrient supply through water, fertiliser, and manure

Farm	**Crop**	**Area**	**Water**	**Nutrients**			**N supply**				**P supply**				**K supply**			
		dunum	**application**	N	P	K	water	fertiliser	manure	**Total**	water	fertiliser	manure	**Total**	water	fertiliser	manure	**Total**
			m3	g/m3	g/m3	g/m3	Kg	Kg	Kg	**Kg**	Kg	Kg	Kg	**Kg**	Kg	Kg	Kg	**Kg**
A1	Alfalfa	6.1	15936.3	90.0	19.0	41.8	1434.3	0.0	26.7	**1461.0**	302.8	0.0	10.0	**312.8**	666.1	0.0	38.0	**704.1**
B1	Alfalfa	30.5	94550.0	85.0	19.0	39.1	8036.8	0.0	0.0	**8036.8**	1796.5	0.0	0.0	**1796.5**	3696.9	0.0	0.0	**3696.9**
B2	Apricot	14.4	746.2	66.0	19.0	37.9	49.2	21.0	54.7	**124.9**	14.2	0.0	17.9	**32.1**	28.3	30.0	45.2	**103.5**
C1	Cucumber	1.4	675.0	27.5	5.3	38.1	18.6	14.0	75.0	**107.6**	3.6	9.3	33.0	**45.9**	25.7	14.8	125.0	**165.5**
	Tomato	1.1	712.8	27.5	5.3	38.1	19.6	11.2	130.0	**160.8**	3.8	7.4	39.2	**50.4**	27.2	19.4	75.2	**121.8**
C2	Onion	3.8	2112.0	32.0	7.1	37.0	67.6	43.8	27.1	**138.5**	15.0	0.0	8.9	**23.9**	78.1	38.2	28.2	**144.5**
	Cucumber	2.2	972.0	32.0	7.1	37.0	31.1	28.0	75.0	**134.1**	6.9	11.4	33.0	**51.3**	36.0	21.6	125.0	**182.6**
C3	Potato	8.7	2320.0	28.9	6.1	33.2	67.0	100.1	87.0	**254.1**	14.2	27.4	28.4	**70.0**	77.0	33.2	90.5	**200.7**
	Tomato	4.5	2993.1	28.9	6.1	33.2	86.5	156.8	150.0	**393.3**	18.3	32.8	65.1	**116.2**	99.4	147.6	250.0	**497.0**

Appendix 8.7

Nitrogen mass balance

Farm	**Crop**	**Measured area**	**N inflow**					**N outflow**		**N storage**
		dunum	water	fertiliser	manure	**Total**		**Harvest**		
			Kg	Kg	Kg	Kg	**kg/ha**	kg	**kg/ha**	**kg/ha**
A1	Alfalfa	6.1	1434.3	0.0	26.7	1461.0	**2395.1**	1265.6	**2074.8**	**320.3**
B1	Alfalfa	30.5	8036.8	0.0	0.0	8036.8	**2635.0**	7301.7	**2394.0**	**241.0**
B2	Apricot	14.4	49.2	21.0	54.7	124.9	**86.7**	30.0	**20.8**	**65.9**
C1	Cucumber	1.4	18.6	20.0	75.0	113.6	**811.4**	51.5	**367.9**	**443.6**
	Tomato	1.1	19.6	16.0	130.0	165.6	**1505.5**	88.2	**801.8**	**703.6**
C2	Onion	3.8	67.6	43.8	27.1	138.5	**364.5**	52.7	**138.7**	**225.8**
	Cucumber	2.2	31.1	28.0	75.0	134.1	**609.5**	53.6	**243.6**	**365.9**
C4	Potato	8.7	67.0	234.0	87.0	388.0	**446.0**	243.6	**280.0**	**166.0**
	Tomato	4.5	86.5	188.2	150.0	424.7	**943.8**	153.0	**340.0**	**603.8**

Phosphorus mass balance

Farm	**Crop**	**Measured area**	**P inflow**					**P outflow**		**P storage**
		dunum	water	fertiliser	manure	**Total**		**Harvest**		
			Kg	Kg	Kg	Kg	**kg/ha**	kg	**kg/ha**	**kg/ha**
A1	Alfalfa	6.1	302.8	0.0	10.0	312.8	**512.8**	177.8	**291.5**	**221.3**
B1	Alfalfa	30.5	1796.5	0.0	0.0	1796.5	**589.0**	1022.2	**335.1**	**253.9**
B2	Apricot	14.4	14.2	0.0	17.9	32.1	**22.3**	1.5	**1.0**	**21.3**
C1	Cucumber	1.4	3.6	12.0	33.0	48.6	**347.1**	7.1	**50.7**	**296.4**
	Tomato	1.1	3.8	9.5	39.2	52.5	**477.3**	9.2	**83.6**	**393.6**
C2	Onion	3.8	15.0	0.0	8.9	23.9	**62.9**	4.9	**12.9**	**50.0**
	Cucumber	2.2	6.9	11.4	33.0	51.3	**233.2**	6.3	**28.6**	**204.5**
C3	Potato	8.7	14.2	36.5	28.4	79.1	**90.9**	13.9	**16.0**	**74.9**
	Tomato	4.5	18.3	36.7	65.1	120.1	**266.9**	22.5	**50.0**	**216.9**

Potassium mass balance

Farm	**Crop**	**Measured area**	**K inflow**					**K outflow**		**K storage**
		dunum	water	fertiliser	manure	**Total**		**Harvest**		
			Kg	Kg	Kg	Kg	**kg/ha**	kg	**kg/ha**	**kg/ha**
A1	Alfalfa	6.1	666.1	0.0	38.0	704.1	**1154.3**	693.1	**1136.2**	**18.0**
B1	Alfalfa	30.5	3696.9	0.0	0.0	3696.9	**1212.1**	3569.7	**1170.4**	**41.7**
B2	Apricot	14.4	28.3	30.0	45.2	103.5	**71.9**	21.3	**14.8**	**57.1**
C1	Cucumber	1.4	25.7	19.8	125.0	170.5	**1217.9**	38.2	**272.9**	**945.0**
	Tomato	1.1	27.2	28.4	75.2	130.8	**1189.1**	68.4	**621.8**	**567.3**
C2	Onion	3.8	78.1	38.2	28.2	144.5	**380.3**	47.9	**126.1**	**254.2**
	Cucumber	2.2	36.0	21.6	125.0	182.6	**830.0**	36.2	**164.5**	**665.5**
C3	Potato	8.7	77.0	33.2	90.5	200.7	**230.7**	181.0	**208.0**	**22.6**
	Tomato	4.5	99.4	179.9	250.0	529.3	**1176.2**	187.0	**415.6**	**760.7**

Appendix 8.7 Treated sewage water as a crop nutrient source, expressed in percentage

Farm	**Crop**	**Area**	**Treated sewage water as nutrient source**		
		dunum	Harvested outflow		
			% N	**% P**	**% K**
A1	Alfalfa	6.1	**113.3**	**170.3**	**96.1**
B1	Alfalfa	30.5	**110.1**	**175.8**	**103.6**
B2	Apricot	14.4	**164**	**946.7**	**132.9**
C1	Cucumber	1.4	**37.7**	**15.8**	**70.2**
	Tomato	1.1	**28.6**	**53.5**	**51.1**
C2	Onion	3.8	**154**	**365.9**	**195.7**
	Cucumber	2.2	**64.5**	**121.1**	**110.4**
C3	Potato	8.7	**29.7**	**110.1**	**46**
	Tomato	4.5	**64.1**	**92**	**60.2**

Summary

Most of Jordan is arid and water resources are limited. This situation becomes more acute the more Jordan develops. New techniques in agriculture, industry and the domestic sector place an increasing demand upon clean and safe water. Good-quality water is hardly available. Unconventional water sources, including treated sewagewater, must be considered as alternative sources. This book focuses on treated sewagewater as a nutrient and water resource for agriculture. We expect that treated sewagewater use in agriculture will minimise farmers' demand for clean, purified, and therefore expensive, water and for chemical fertilisers.

Treated sewagewater use in agriculture maintains environmental quality. Also other national goals, such as the creation of sustainable agriculture and the protection of scarce water sources, are thus served. Another advantage is the possibility of decreasing the necessary purification level. Costs for treatment, thanks to the role of soil and crops in acting as a bio-filter, will thus decrease. Moreover, using the nutrients present in treated sewagewater may diminish fertilisation costs. But disadvantages should also be considered. Treated sewagewater use in irrigation could be hazardous to the environment, since the influent, and hence the effluent, contains pollutants such as macro-organic matter, trace elements, pathogenic micro-organisms and ions.

Use of treated sewagewater in Jordan is not a new idea. Advantages and disadvantages should be studied. However, what kind of research is then needed? Most scientific approaches in research are done under objectified, controlled conditions. Such experiments do not reflect the everyday reality of the farmers. Moreover, experimental research in agriculture does not always reflect the interests of Jordanian farmers. Another type of research is therefore needed. We need research that integrates Gamma and Beta sciences, farmers and scientists, and the environment and agricultural production. Prototyping, a mix of experimental farm research and agronomic designing is an answer to those needs. The technique has been used successfully in almost all European countries. The question was therefore, "why not be tested and used in Jordanian conditions"?

We focused on designing, testing and improving theoretical prototypes of treated sewagewater using farms. A pilot group of six farmers was formed in three different zones of the study area, with a selection of six different crops (Alfalfa, Apricot, Tomato, Cucumber, Onion and Potato). Lessons, methods, techniques and recommendations gained from many experiments done on treated sewagewater use in crop production in Mediterranean countries were integrated and introduced into farming methods. Farmers started the conversion process and learned how to deal with treated sewagewater for irrigation. The purpose of this study is to design treated sewagewater using farms and to teach farmers to rely on their own skills and information. So not only hard knowledge became involved. The training of farmers and the developing of their managerial skills also became part of the problem statement. In particular, we created a situation of farm system research. Farmers had to do the job, facilitated by researchers. Farmer and facilitator tried to find a new balance between economical and socio-environmental goals.

Chapter 1 looks at the consequences of Jordan's water shortages as a result of domestic, agricultural and industrial consumption. This chapter explores the actions recommended in the Dublin statement to overcome the over-consumption and pollution as well as the Jordan's law of Environmental Protection for the formulation of an effective environmental policy. It also shows the urgency in developing WASTEVAL programme for capacity building at the counterpart institutes in the Netherlands, Jordan, Egypt and the West Bank concerning wastewater valorisation for agricultural production in the Middle East area by using low-cost treatment technologies. This chapter concludes that designing treated sewagewater using farms must bring different stakeholders together. Policy-makers and planners who set the conditions for water purification must also be involved. As the WASTEVAL programme is about research and education concerning water scarcity in Middle East countries and this book especially reports about research results obtained in Jordan, we had to begin with describing Jordan's actual water deficit.

The **second chapter** acquaints the reader among others, that limited clean water resources presented the main constraint for agricultural development. The deficit between supply and demand was 307 million m^3 in 1998 and is projected to increase to 360 million m^3 in 2020. At the same time, treated sewagewater will increase from 67 million m^3 in 1998 to 232 million m^3 in 2020. Chapter 2 gives the reader a sense of urgency: somebody must do something and quickly in order to stop the increasing shortage of clean water of Jordan. Agronomic, environmental, legislative and socio-cultural aspects of treated sewagewater are presented. It is shown that a farming system that could adequately address these aspects requires: integration of agro-technical, agro-ecological and agro-economical knowledge, joint agreement on normative objectives among stakeholders, and empirical team work to test, adapt and refine those farms under real commercial conditions and the promotion of the concept for rural development. Chapter 2 also demonstrates that among the all water users of Jordan, the agricultural sector is the most serious one. Jordanian agriculture, as big polluter of natural resources, according the 'polluter pays' principle, must learn as first how to produce well by low application levels of synthetic agro-chemicals. Stimulating the agricultural sector to use treated sewagewater for irrigation purposes only could redress the very negative water balance of Jordan. But first, the marginality of Jordanian farming, high production level demand of commodities for export and consumers not willing to pay more for their food, must be overcome.

In **Chapter 3** attention is given to the theoretical framework which addresses the co-operation and responsibilities of treated sewagewater producing and using sectors. Chapter 3 shows a model for how Jordanian farmers could be involved in decreasing their water use and pollution during crop production. It is assumed that sewagewater, after certain pre-treatment, carries along sufficient nutrients that could function as fertiliser and as water dose during primary production. As a consequence, supply of chemical fertiliser could be reduced considerably. Three advantages thus emerge. Cost for sewagewater cleaning becomes lower, the variable costs of farmers decrease and water demand of the agricultural sector moves from clean (cleansed or natural) water to treated sewagewater. The model assumes that aforementioned advantages just appear when the treated sewagewater producing and using sectors work together. Co-operation leads to harmonisation of end terms for quality goals of sewagewater, to recognition and accepting each other's working procedures and to cohesion among investments for intake and distribution of sewagewater. Co-operation will also lead to effective sharing of knowledge, sharing of concepts and definitions as well as to efficient regulation and the control over it. Co-operation will not come into being by itself. Both sectors are much too different for that. Therefore the model assumes that the government must facilitate such a co-operation.

Chapter 4 translates the theoretical framework from chapter 3 in six research questions that had to be addressed during project's time. Each of them becomes answered in the chapters 5 to 10. Those chapters are set up as if they were separate publications. The reader will notice that between them some overlap may be found. That was, considering the holistic approach of this research unavoidable. On the other hand overlap also indicates that our approach of the problem statement from chapter 3 happened in an integrated way.

Chapter 5 is about the way we looked for a suitable research site. Selected study areas had to offer conditions for concerted research by facilitated farmers. Three zones were identified. Each of them represented different levels of treated sewagewater quality and has sufficient conditions for the collection of reliable information about how farmers could use treated sewagewater for plant production. This provided comparative information on the potentials of treated sewagewater use in Jordan. Concerning the participation of farmers in the three different zones of our research area, I conclude that farmers were willing to co-operate on my terms (participation for the full duration of research, prepared to attend regular meetings with colleagues and researchers, and willing to provide data for publication). Furthermore, I found a serious gap between the perception of what scientists see as farmers' problems and what farmers themselves see as their problems. It was good to know this from the outset, as this knowledge made us consistently aware of our attitude towards farmers. I decided to act as an interrogator, rather than as a specialist who gives answers to questions never raised. I considered the farmer a relevant source of knowledge.

Chapter 6 shows what consequences of working with farmers on their fields had to taken into account when starting the research. A conceptual model is presented in this chapter showing the steps that farmers and researchers have to go through during the whole research process. The farmers accepted the model as they feel that they got a clear place in the process. This chapter also presents a decision platform model where researcher and farmer learn to work together. The platform function as a school where farmers are trained in becoming better observers and managers of their land and researchers are trained in relying on farmers' experiences.

Chapter 7 outlines the suitability of treated sewagewater for irrigation in the study area by using different parameters like electrical conductivity of water (EC_w), total dissolved solid values, sodium adsorption ratio, ion toxicity, total nitrogen and total phosphorus values, pH and microbiological quality. The suitability of treated sewagewater was assessed, based on World Health Organisation (WHO) and Food and Agriculture Organisation (FAO) guidelines. The potential hazards in relation to public health and irrigation use were identified. The Jordanian regulations governing treated sewagewater use were reviewed, and necessary management practices outlined. An assessment of treated sewagewater for manuring purposes and the salination effects involved are also presented. Chapter 7 demonstrates that treated sewagewater may cover crop demands on nutrients and water, without chemical fertiliser supply.

Chapter 8 outlines the three sources of information used to conduct an informal survey, namely, regional stakeholders, literature and field observation. Chapter 8 presents how small-scaled farmers in the research site redesigned their farms in a way that they could use treated sewagewater safe and well. This design is based on the prototyping technique used in many European countries. It also outlines the processes for establishing:

- The objectives of treated sewagewater using farms to be achieved in the future. A diagnosis of the existing situation of treated sewagewater use was made first. Besides this, the targeted contribution of the designed prototype in the long-term improvement of the treated sewagewater use situation in the area will be determined. The diagnosis and grading of objectives (prioritisation) should therefore be done in collaboration with the major actors involved in treated sewagewater use, and after careful examination of all available resources, agro-technology, experiences and knowledge.
- The translation and quantification of the objectives into suitable parameters. It is based on the careful examination and selection of parameters related to the objectives and the production system, and determines the quantification of the objectives of treated sewagewater use in irrigation. The criterion of being integrated in, or being indispensable to, a single objective was used for the parameter selection. In this way, the quantified objectives can be used as desired results, to evaluate the achieved results of the treated sewagewater use in irrigation prototypes. This step provides eleven parameters for treated sewagewater use.
- Relevant farming methods and techniques. The farming methods are nutrient management, water management and farm structure optimisation.
- Theoretical prototype. The theoretical prototype should secure the inter-linking of the new methods at all crop production levels: physical, biological-agronomic, product-market, and farm level. Otherwise objectives would not be achieved and the sustainability and productivity of the crop will be adversely effected.
- Testing of new farm designs in pilot farms.

The initial results of practical application are presented. Practical application of the prototypes showed that participant farmers need a lot of training and data. Initial results clearly show that our design needs further improvement by progressive retesting procedures. Initial results also show the impact of former conventional farming methods. Farmers acquired a greater understanding about the damage which current agro-technological methods cause to relevant natural resources, as well as to their future prospects of farming. Many retesting cycles are required to get rid of the negative impacts of current agro-technological methods.

The last part of the study outlines the main elements for a strategy of prototype improvement. Chapter 9 presents strengths and weakness analysis concerning the redesigned farms. This chapter also presents a simple SWOT analysis to study and explore further development of treated sewagewater prototype in Jordan. The results of this analysis were formulated in terms of desired government policy, research and extension services. This chapter concluded that farmers can only progress if they work for the development of certification systems that they initiate and manage themselves. Chapter 10 shows the role of stakeholders in safe use of treated sewagewater on farms. This chapter emphasis on the co-operation between the treated sewagewater producing and using sector. The study ends with a conclusion and recommendations regarding the proposed approach for treated sewagewater use in irrigated agriculture (chapter 11).

Samenvatting

Het grootste deel van Jordanië is droog en wat er aan water aanwezig is, is schaars. Deze situatie wordt nijpender naarmate Jordanië zich ontwikkelt. Nieuwe technologieën in de landbouw, industrie en huishoudens houden een toenemende vraag naar schoon en veilig water in. Water van hoge kwaliteit is nauwelijks verkrijgbaar. Alternatieve en daarom ook niet algemeen geaccepteerde waterreserves, behandeld rioolwater incluis, moeten hoe dan ook, in beschouwing worden genomen. Dit boek gaat over behandeld rioolwater als nutriënten en watertoeleveraar voor de landbouw. We nemen aan dat door het gebruik van behandeld rioolwater in de landbouw, de vraag van boeren naar schoon, gereinigd en daarom ook duur water, alsmede de vraag naar kunstmest kleiner zal worden.

Behandeld rioolwater voor gebruik in de landbouw mag de kwaliteit van het milieu niet beïnvloeden. Maar ook andere nationale doelstellingen, zoals de ontwikkeling van duurzame vormen van landbouw en de bescherming van schaarse waterbronnen, dienen mogelijk te blijven. Een ander voordeel zou kunnen zijn dat de mate van rioolwaterreiniging met minder eisen zou kunnen volstaan. De kosten voor waterreiniging zouden, dankzij de rol die de bodem en gewassen als biofilter zouden spelen, kunnen afnemen. Bovendien zou het gebruik van de nutriënten aanwezig in behandeld rioolwater, de kosten voor bemesting omlaag kunnen brengen. Ook de nadelen zullen in overweging genomen moeten worden. Immers, behandeld rioolwater als irrigatiebron kan het milieu schaden, omdat zowel in- als effluents vervuilende stoffen als grof organisch materiaal, spore-elementen, pathogenen en ionen, bevat.

Het idee van gebruik van behandeld rioolwater in Jordanië is niet nieuw. De voor- en nadelen van gebruik in de landbouw verdient verdere studie. Maar wat voor onderzoek is dan noodzakelijk? Het merendeel van dergelijk onderzoek wordt gedaan onder geobjectiveerde en gecontroleerde proefomstandigheden. Dergelijke experimenten weerspiegelen echter onvoldoende de dagelijkse werkelijkheid van boeren. Bovendien blijkt experimenteel landbouwkundig onderzoek niet altijd een weerspiegeling te zijn van wat boeren interesseert. Een ander type van onderzoek is daarom gewenst. We hebben behoefte aan onderzoek dat kennis uit zowel de bèta- als de gammawetenschappen, kennis afkomstig van boeren en van wetenschappers en kennis over het milieu en de agrarische productie integreert. Protypering, een techniek die berust op zowel experimenteel onderzoek op boerenbedrijven en agronomisch ontwerpen, is een mogelijk antwoord op die behoefte. De techniek is met veel succes in bijna alle landen van de Europese Unie toegepast geweest. De vraag was daarom “waarom ook niet in Jordanië geprobeerd”?

We hebben onze aandacht gericht op het ontwerp, de test en de aanpassing van ideaaltypische modellen van landbouwproductiebedrijven die behandeld rioolwater gebruiken. Daartoe werd een groep van zes boeren in drie verschillende zones binnen ons onderzoeksgebied aangezocht om met een keuze voor zes verschillende gewassen (alfalfa, abrikoos, tomaat, komkommer, ui en aardappel) in het onderzoek mee te doen. Ervaringen, methodieken, technieken en aanbevelingen, verkregen uit de vele experimenten, die met de productie van gewassen geïrrigeerd met behandeld rioolwater rondom het Middellandse zeegebied werden gedaan, werden meegenomen en gebruikt bij de ontwikkeling van bedrijfsmethoden in de proefbedrijven. De boeren voerden de omschakeling uit en leerden daarbij hoe zij met behandeld rioolwater als irrigatiebron moeten omgaan. Het doel van dit onderzoek was gericht op ontwerpen van landbouwproductiebedrijven die behandeld afvalwater gebruiken en op onderwijzen van boeren hoe zij op eigen vaardigheden en ervaringen kunnen vertrouwen. Daarmee werd dus niet alleen geleund op ‘harde’ kennis. Ook de training van boeren en de ontwikkeling van hun managementvaardigheden waren onderdeel van de probleemstelling. Eigenlijk schiepen wij een landbouwbedrijfsgebonden onderzoekssituatie. De boeren dienden het onderzoek te verrichten, maar werden daarbij ondersteund door onderzoekers. Boer en onderzoeker probeerden samen een nieuwe balans te vinden tussen economische en sociaal-economische doelstellingen.

Hoofdstuk 1 staat stil bij de gevolgen van het watertekort van Jordanië als gevolg van huishoudelijk, landbouwkundig en industrieel gebruik van water. Dit hoofdstuk onderzoekt de acties die in het Dublin-akkoord betreffende het overmatige gebruik en vervuiling van water zijn vastgelegd, als ook die welke volgen uit Jordaanse milieuwetgeving gericht op de ontwikkeling van effectief milieubeleid. Het laat ook de noodzaak zien van het Nederlands, Jordaanse, Egyptische en West Bank-samenwerkingsprogramma WASTEVAL, dat gericht is op de ontwikkeling van expertise en inzicht bij instituten werkzaam op gebied van benutting van afvalwater voor agrarische productie in het Midden-Oosten door toepassing van goedkope reinigingstechnieken. Dit hoofdstuk concludeert dat voor het ontwerp van landbouwproductiebedrijven, die gebruik maken van behandeld rioolwater, samenwerking noodzakelijk is tussen de verschillende belangengroeperingen die daarbij van belang zijn. Ook beleidsmakers en planners die bepalend zijn voor waterreiniging moeten worden betrokken. Omdat het WASTEVAL-programma over onderzoek en onderwijs gaat betreffende watertekorten in landen van het Midden Oosten en dit boek in het bijzonder rapporteert over de onderzoeksresultaten die in Jordanië zijn verkregen, dienden we te beginnen met de beschrijving van de actuele watertekorten van Jordanië.

Het tweede hoofdstuk maakt duidelijk dat de ontwikkeling van de landbouw voornamelijk wordt beperkt door het gebrek aan bronnen met schoon water. Het watertekort (verschil tussen aanbod en vraag) bedroeg in 1998 307 miljoen kubieke meter en zal tegen 2020 waarschijnlijk tot 360 miljoen kubieke meter zijn toegenomen. In dezelfde tijd zal de hoeveelheid behandeld rioolwater van 67 miljoen kubieke meter in 1998 tot 232 miljoen kubieke meter in 2020 zijn toegenomen. Hoofdstuk 2 geeft de lezer een gevoel van urgentie: iemand moet iets doen en snel ook, teneinde het toenemende tekort aan schoon water in Jordanië het hoofd te kunnen bieden. Agronomische, milieukundige, juridische en sociaal culturele aspecten van behandeld riool water worden gepresenteerd. Aangetoond wordt dat een landbouwbedrijf dat desbetreffende aspecten op juiste wijze tegemoet treedt, behoefte heeft aan: integratie van agro-technische, agro-ecologische en agro-economische kennis en overeenstemming tussen betrokkenen over normstelling en praktische samenwerking om dergelijke bedrijven uit te proberen, aan te passen, te verfijnen onder werkelijke commerciële situaties. Hoofdstuk 2 laat ook zien dat de landbouwsector de grootste gebruiker en vervuiler van water is. De Jordaanse landbouw als grootste vervuiler van natuurlijke hulpbronnen, moet daarom als eerste leren hoe het “de vervuiler betaalt principe” toepast en hoe er met minder agro-chemicaliën toch goed kan worden geproduceerd. Alleen door de landbouwsector er toe te bewegen om behandeld rioolwater te gaan gebruiken voor irrigatiedoeleinden kan de zeer negatieve waterbalans van Jordanië belangrijk worden teruggebracht. Om dat mogelijk te maken, zal eerst de marginaliteit van de Jordaanse landbouw, het hoge productieniveau van exportproducten en de onwelwillendheid van consumenten om meer voor hun voedsel te gaan betalen, aangepakt moeten worden.

In hoofdstuk 3 wordt aandacht besteed aan het theoretisch raamwerk die aan de samenwerking en verantwoordelijkheden van behandeld riool water gebruikende en producerende sectoren vorm moet geven. Hoofdstuk 3 geeft een model voor de manier waarop Jordaanse boeren zouden kunnen worden betrokken bij hun vermindering van het watergebruik en vermindering van de milieuvervuiling tijdens de productie. Aangenomen is dat riool water, na een zekere behandeling, voldoende nutriënten met zich mee brengt. Dit rioolwater zou als bemestingsstof en als watergift kunnen worden gebruikt tijdens de primaire productie. Het gevolg daarvan zou zijn dat de toediening van kunstmest aanzienlijk teruggebracht kan worden. Op die manier ontstaan er drie voordelen. De kosten voor rioolwaterreiniging nemen af, de variabele kosten voor de boeren worden kleiner en de behoefte aan water vanuit de landbouwsector verschuift van schoon (schoongemaakt en natuurlijk) water naar behandeld rioolwater. Het model gaat er vanuit dat de zojuist genoemde voordelen alleen zichtbaar worden wanneer behandeld rioolwater gebruikende en producerende sectoren met elkaar samenwerken. Samenwerking leidt tot harmonisatie van de eindnormen die de kwaliteit van behandeld rioolwater bepalen, tot wederzijdse erkenning van elkaars werkwijzen en tot afstemming van investeringsgedrag ten behoeve van waterinname en distributie van rioolwater. Samenwerking zal leiden tot effectieve deling van kennis, deling van concepten en definities als ook van een efficiënte regelgeving en het toezicht daarop. Samenwerking zal niet als vanzelf ontstaan. Daarvoor zijn beide sectoren te verschillend. Daarom gaat het model er ook vanuit dat de overheid een faciliterende rol dient te spelen.

Hoofdstuk 4 zet het theoretisch raamwerk uit hoofdstuk 3 om in de zes onderzoeksvragen die tijdens het project aan de orde moeten komen. Elk wordt afzonderlijk behandeld in de hoofdstukken 5 tot 10. Die hoofdstukken zijn opgezet als ware het afzonderlijke publicaties. De lezer zal zien dat daartussen enige overlap kan voorkomen. Dat was, gezien de holistische benaderingswijze van het onderzoek niet te vermijden. Maar aan de andere kant getuigt overlap ook van het feit dat de aanpak van het probleem op geïntegreerde wijze is gebeurd.

Hoofdstuk 5 gaat over de wijze waarop gezocht werd naar de meest geschikte plaats voor onderzoek. De verkozen gebieden dienden mogelijkheden te scheppen voor intensieve samenwerking door boeren die ook worden ondersteund. Er werden drie zones vastgesteld. Elke zone representeerde verschillende kwaliteitsniveaus van behandeld rioolwater en voldeed aan voldoende randvoorwaarden voor de verzameling van betrouwbare informatie over hoe boeren behandeld rioolwater voor gewasproductie zouden kunnen gebruiken. Dit leverde vergelijkende informatie over de mogelijkheden van het gebruik van behandeld rioolwater in Jordanië. Wat betreft de boeren die in de drie verschillende zones van ons onderzoeksgebied met ons wilden meewerken, stelden we vast dat zij onze voorwaarden daartoe aanvaardden (w.o. hun participatie gedurende de gehele periode van het project, bereidheid om regelmatig te houden bijeenkomsten van onderzoekers en collega-boeren bij te wonen en de bereidheid om gegevens te verschaffen die in het onderzoek mogen worden gebruikt).
We vonden verder dat er een flink verschil in perceptie bestond tussen wat wetenschappelijke onderzoekers beschouwen als het probleem van de boer en wat de boeren daar zelf over te zeggen hebben. Het was goed om dit vooraf te weten omdat zulke informatie ons steeds bewust maakte van de manier waarop wij met de boeren omgingen. Ik besloot daarom om meer als vragensteller op te treden dan als specialist die antwoord pleegt te geven op vragen die niet werden gesteld. Ik ging ervan uit dat boeren relevante bronnen van bruikbare kennis waren.

Hoofdstuk 6 laat zien welke consequenties van het werken met boeren in hun bedrijven, bij het begin van het onderzoek, in beschouwing dienden te worden genomen. Een schema van stappen die door boeren en onderzoekers tijdens de uitvoering van het hele project moeten worden genomen, wordt voorgesteld. Het bleek dat de boeren het stappenschema accepteerden omdat zij het gevoel erbij kregen dat zij een duidelijke rol in het proces speelden. Dit hoofdstuk presenteert ook het idee van een besluitvormende groep waarin onderzoekers en boeren leren hoe zij moeten samenwerken. De groep functioneerde als scholingsmoment waarop boeren leerden om binnen hun bedrijf beter te observeren en het beter te managen. Onderzoekers werden getraind om beter op boerenkennis te vertrouwen.

Hoofdstuk 7 maakt duidelijk in hoeverre behandeld rioolwater geschikt is voor irrigatie in het onderzoeksgebied door toepassing van verschillende parameters zoals de elektrische geleidbaarheid van water (EC_w), totaal opgeloste vaste deeltjes, natrium absorptie, ion toxiciteit, totaal stikstof en totaal fosfaat, pH en microbiële kwaliteit. De geschiktheid van behandeld rioolwater werd bepaald en gebaseerd op de richtlijnen van de WHO en de FAO. De potentiële gevaren in verband met de volksgezondheid en het gebruik ervan als irrigatie water werden vastgesteld. De Jordaanse regelgeving, bepalend voor de toepassing van behandeld rioolwater, werd geïnventariseerd en de noodzakelijk geachte omgang ervan in de praktijk geïdentificeerd. Ook het gebruik van behandeld afvalwater voor bemestingsdoeleinden werd nagegaan, alsmede van de verziltingseffecten. Uit hoofdstuk 7 blijkt dat behandeld rioolwater de nutriënten- en waterbehoeften van het gewas zonder gebruik van kunstmest kan dekken.

Om een begin van onderzoek mogelijk te maken is in hoofdstuk 8 uitgegaan van drie informatiebronnen: namelijk die van de regionale belangengroeperingen, de literatuur en eigen veldwaarnemingen. Hoofdstuk 8 laat zien hoe kleinschalige boeren tijdens het project hun bedrijven zodanig herontwierpen dat zij behandeld rioolwater veilig en goed konden gebruiken. Het ontwerpproces is gebaseerd op de prototyperingsmethode die in vele landen van Europa werd toegepast. De hoofdpunten van het ontwerpproces die in dit hoofdstuk zijn aangegeven, omvatten:

- **De doelstellingen die een behandeld rioolwater gebruikende bedrijf voor de toekomst heeft**. Daartoe werd eerst de bestaande situatie met het gebruik van behandeld rioolwater vastgesteld. Daarnaast werd bepaald welke bijdrage een ontworpen prototype van een landbouwbedrijf in de toekomst moet leveren aan de verbetering van het gebruik van behandeld afvalwater in het gebied. De vaststelling daarvan en de volgorde waarin de doelstellingen moeten worden gerealiseerd vergt samenwerking met de boeren die behandeld rioolwater zullen gaan gebruiken. Samen wordt gekeken naar alle beschikbare waterbronnen, agrotechnologie, ervaringen en kennis.

- **De vertaling van de doelstellingen en de kwantificering daarvan van de doelstellingen in geschikte parameters.** Dit proces wordt gebaseerd op nauwkeurig onderzoek van de doelstellingen en de selectie van parameters die met de doelstellingen en het productiebedrijf verband houden. Het resultaat is de kwantificering van de doelstellingen voor het gebruik van behandeld rioolwater in irrigatie. Niet alle doelstellingen kunnen in een keer worden nagestreefd. In het begin moeten er keuzes worden gemaakt. Dat werd gedaan op basis van criteria als de mate waarin het aan de realisatie van meer dan een doelstelling bij kan dragen of de mate van onmisbaarheid tijdens het omschakelingsproces. De gekwantificeerde doelstellingen konden aldus als de na te streven resultaten van het gebruik van behandeld rioolwater in prototypes van irrigatie worden gebruikt. Uit deze stap kwamen elf parameters voor het gebruik van behandeld rioolwater naar voren.
- **Zinvol te gebruiken productiemethoden en technieken.** Dit betrof nutriënt management, water management en optimalisatie van de bedrijfsstructuur.
- **Het theoretische prototype.** Het theoretische prototype moet duidelijk maken hoe de nieuwe productiemethoden op alle gewasproductieniveaus (fysiek, biologisch-landbouwkundig, afzetmarkt en bedrijfsniveau) doorwerkt. Als dat niet gedaan zou worden zullen de beoogde doelstellingen niet op samenhangende wijze kunnen worden nagestreefd en de duurzaamheid en productiviteit van het gewas negatief beïnvloeden.
- **Uitproberen van de nieuwe bedrijfsontwerpen in de praktijk.**

De eerste resultaten na invoering van het theoretische prototype in de praktijk worden weergegeven. De resultaten laten zien dat deelnemende boeren veel training en gegevens nodig hebben. Het wordt duidelijk dat ons ontwerp verdere verbeteringen behoeft via meerdere testen in de praktijk. De eerste resultaten tonen ook welke invloed vroegere en conventionele productiemethoden hadden. Boeren moeten meer begrip ontwikkelen over de schade die gangbare landbouwmethodes kunnen meebrengen voor belangrijke natuurlijke hulpbronnen alsmede voor de toekomstige positie van hun bedrijf. Via opeenvolgende herontwerpcycli zullen de negatieve invloeden van gangbare productietechnieken moeten worden uitgebannen.

Het laatste onderdeel van ons onderzoek wordt gewijd aan de hoofdelementen van een strategie gericht op verbetering van de prototypes. Hoofdstuk 9 gaat in op de sterkten en zwakten van de herontworpen bedrijven. Dat gebeurde via een eenvoudige SWOT-analyse waarmee werd nagegaan wat er nodig is om de verdere ontwikkeling van Jordaanse bedrijven die behandeld rioolwater gebruiken te ondersteunen. De resultaten hiervan werden geformuleerd in termen voor overheidsbeleid, voor onderzoeksbeleid en voor dienstverlening aan boeren en mensen werkzaam in de rioolwatersector. Duidelijk wordt dat boeren alleen vooruit zullen komen wanneer zij hun communicatie met de markt kunnen verbeteren en wel door middel van een toezichtsysteem op de kwaliteit van hun productie. Een zodanig certificatiesysteem zou in eerste instantie een initiatief kunnen zijn van de boeren die behandeld rioolwater zijn gaan gebruiken. Uit hoofdstuk 10 komt naar voren welke rol alle belangengroeperingen bij het veilige gebruik van behandeld rioolwater in productiebedrijven spelen. Dit hoofdstuk komt weer terug op de noodzaak van samenwerking tussen de behandeld afvalwater gebruikende en producerende sectoren. Het verslag eindigt met hoofdstuk 11 waarin conclusies worden getrokken en een serie van aanbevelingen naar voren komen om de in dit onderzoek voorgestelde benadering voor veilig gebruik van behandeld rioolwater in de praktijk van de landbouw mogelijk te maken.

Summary in Arabic

ملخص

يعتبر الأردن قاحل ومحدود المصادر المائية. وتزداد هذه المشكلة حدة كلما تطور الأردن ، كما أن التقنيات الحديثة المستخدمة في الزراعة والصناعة وقطاع المنازل تتطلب المزيد من المياه النظيفة السليمة ، وبما أنه من الصعب توفر نوعية مياه جيدة تكفي كل هذه الأغراض كان لا بد من التفكير بمصادر مياه غير التقليدية بما في ذلك معالجة مياه الصرف الصحي كمصادر تعويض.

يركز هذا الكتاب على استخدام مياه الصرف الصحي المعالجة كمصدر مياه ومادة مغذية في القطاع الزراعي ، ونتوقع أن استخدام مياه الصرف الصحي المعالجة في الزراعة سيقلص من طلب المزارعين على المياه النظيفة النقية والغالية الثمن ومن الطلب على السماد الكيماوي أيضا.

يحافظ استخدام مياه الصرف الصحي المعالجة في الزراعة على نوعية البيئة كما ويخدم أهداف وطنية أخرى تتمثل في خلق زراعة مستدامة وحماية مصادر المياه الشحيحة. ومن فوائدها أيضا احتمالية تقليص مستوى التنقية اللازمة نظرا إلى دور المرشح الحيوي الذي ستلعبه التربة والمحاصيل ، مما سيؤدي بالتالي إلى انخفاض تكاليف المعالجة. إضافة إلى ذلك فإن المواد المغذية الموجودة في مياه الصرف الصحي المعالجة ستقلل من تكاليف استخدام السماد. ومن جهة أخرى فان استخدام مياه الصرف الصحي المعالجة في الري قد يشكل خطرا على البيئة لأن الماء الناتج من محطات التنقية سيحتوي على مواد ملوثة مثل المواد العضوية الكبيرة وعناصر النزرة وكائنات حية صغيرة ممرضة وأيونات.

إن استخدام مياه الصرف الصحي المعالجة في الأردن ليس بالأمر الجديد ، ولا بد من دراسة الجوانب الايجابية والسلبية معا غير أن السؤال الواجب طرحه هو: ما نوع البحث الذي نحتاج إليه للوصول الى أفضل نتيجة؟

تتم معظم المناهج العلمية في البحث ضمن تجارب محددة الأهداف خاضعة للمراقبة. غير أن هذه التجارب لا تعكس واقع الحياة اليومية للمزارعين ، إضافة إلى أن البحث التجريبي في الزراعة لا يعكس اهتمامات المزارعين الأردنيين ، ومن هنا تظهر الحاجة الماسة إلى نوع آخر من البحوث تجمع بين علوم بيتا وغاما وبين المزارعين والعلماء والبيئة والإنتاج الزراعي. والجواب على هذه الاحتياجات يتمثل بالنموذج الأولي والذي هو عبارة عن مزيج من البحث التجريبي في المزارع والتصميم الزراعي. وقد استخدمت هذه التقنية بنجاح في معظم الدول الأوروبية ، ومن هنا نطرح السؤال التالي: لماذا لا تستخدم هذه التقنية ضمن ظروف البيئة الأردنية؟

لقد ركزنا على تصميم وتجربة وتحسين النماذج الأولية النظرية لمعالجة مياه الصرف الصحي واستخدامها في باستخدام المزارع. تم تشكيل مجموعة تجريبية من ستة مزارعين في ثلاث مناطق مختلفة من منطقة البحث مع اختيار ستة محاصيل مختلفة (برسم حجازي، مشمش، بندورة، خيار، بصل وبطاطا). وقد تم إدراج وإدخال الدروس والأساليب والتقنيات والتوصيات المكتسبة من العديد من التجارب السابقة التي أجريت على استخدام مياه الصرف الصحي المعالجة في إنتاج المحاصيل في بلاد البحر الأبيض المتوسط إلى الأساليب الزراعية المستخدمة في النماذج الأولية. وقد استطاع المزارعون القيام بعملية التحول بنجاح ، وتعلموا كيفية التعامل مع مياه الصرف الصحي المعالجة في الري.

تهدف هذه الدراسة بالدرجة الأولى إلى تصميم مزارع قائمة على استخدام مياه الصرف الصحي المعالجة وعلى تعليم المزارعين الاعتماد على مهاراتهم ومعلوماتهم ، وبالتالي لم تعد المشكلة محصورة في البحث العلمي فحسب بل أن تدريب المزارعين وتطويرمهاراتهم الإدارية أصبح يشكل جزءا هاما من مجمل النتائج.

وقد قمنا بتشكيل نظام بحث قائم على المزارع ، وكان على المزارعين أن يقوموا بالمهام الموكلة إليهم من قبل الباحثين. وقد حاول المزارع والباحث معا إيجاد نظام يوازن بين الأهداف الاقتصادية والاجتماعية.

الفصل الأول يبحث في نتائج نقص المياه في الأردن نتيجة للاستهلاك البشري ، والزراعي و الصناعي. هذا الفصل يستكشف توصيات مؤتمر دبلن في التغلب على زيادة استهلاك وتلوث المصادر المائية ، كما أنه يناقش القانون الأردني لحماية البيئة وذلك لصياغة سياسة بيئية فعالة. كذلك يعرض الحاجة إلى تطوير برنامج WASTEVAL لبناء وتطويرقدرات الجهات الرسمية المشاركة من هولندا ، الأردن ، مصر والضفة الغربية والخاصة بدعم وتشجيع استخدام مياه الصرف الصحي في الإنتاج الزراعي في منطقة الشرق الأوسط باستخدام أساليب تكنولوجيا معالجة ذات كلفة منخفضة.

نستخلص من هذا الفصل بأنه لتصميم نظام استخدام المياه المعالجة في المزارع يجب أن نأخذ بعين الاعتبار آراء المشاركين في صناعة القرار والمهندسين الذين يضعون أسس تنقية مياه الصرف الصحي.

إن برنامج WASTEVAL يدور حول البحث و التطوير في مجال ندرة المياه في الشرق الأوسط ، وحيث أن هذا الكتاب يتطرق إلى النتائج المستخلصة في الأردن ، فإنه كان علينا أن نبدأ بتوضيح الوضع المائي الحرج في الأردن.

الفصل الثاني يوضح بان المياه النقية والنظيفة المحدودة تعد العقبة الأساسية أمام تطور الزراعة في الأردن. فالفرق بين كمية المياه المطلوبة والمتوفرة فعليا قد وصلت إلى 307 مليون متر مكعب في عام 1998 ، ومن المحتمل أن تزيد إلى 360 متر مكعب في عام 2020 ، وفي الوقت نفسه ستزيد مياه الصرف الصحي من 76 مليون متر مكعب في عام 1998 إلى 232 مليون متر مكعب في عام 2020. في هذا الفصل تظهر الحاجة الملحة إلى ضرورة القيام بعمل ما وبشكل سريع لإيقاف النقص المتزايد للمياه النظيفة والنقية في الأردن. كما نعرض النتائج الزراعية والبيئية والاجتماعية المترتبة على إستخدام مياه الصرف الصحي المعالجة في الزراعة , وكذلك يبين أن أي نظام زراعي قائم على هذا النظام يتطلب ما يلي: توافق كامل في المعلومات الزراعية التقنية والإقتصادية والبيئية ، اتفاق مشترك على الأهداف المعيارية بين صانعوا القرار ، وإنشاء فريق تجريبي لكي يختبر ويكيف تلك المزارع تحت الشروط الحقيقية ، بالإضافة إلى الأخذ بعين الإعتبار المفهوم الحقيقي للتطور الريفي .

يبين الفصل الثاني أن من أهم استخدامات المياه في الأردن هي القطاع الزراعي. وتعتبر الزراعة اكبر مصدر ملوث للمصادر الطبيعية ، لذلك يجب أن يعي المزارع إلى مبدأ الإنتاج الجيد باستخدام اقل الأسمدة الكيماوية. إن استخدام مياه الصرف الصحي في الري يمكن أن يعيد النظر في الحالة السلبية للتوازن المائي في الأردن لكن أولا يجب التغلب على محدودية الزراعة الأردنية ، والحاجة الزائدة للإنتاج الزراعي لأغراض التصدير ، وعدم قدرة المستهلك لدفع الأكثر مقابل الأفضل.

الفصل الثالث يركز على بناء الهيكل النظري في عمل المزرعة والذي يوضح التعاون بين منتجي مياه الصرف الصحي ومستخدميه في القطاع الزراعي ومسؤوليات كل منهما. كذلك يعرض هذا الفصل نموذج للمزارعين الأردنيين يوضح لهم كيفية المساهمة في خفض نسبة استهلاك المياه والتلوث خلال عملية إنتاج المحاصيل. وقد افترض بان مياه الصرف الصحي المعالجة تحتوي على الكثير من العناصر المغذية والتي يمكن أن تعمل كمادة مخصبة (مسمدة) مما يساعد على التقليل من استخدام الأسمدة الكيماوية. بناء على ذلك ستصبح تكلفة تنقية المياه العادمة قليلة ، ومن ثم يقل عبىء التكاليف الزراعية على المزارعين ، كما أن طلب الزراعة للمياه النظيفة سيقل مقابل استخدام مياه الصرف الصحي المعالجة.

النموذج يفترض بانه يمكن الحصول على جميع تلك الفوائد المذكورة أعلاه عندما يعمل منتجي مياه الصرف الصحي ومستخدميها معا ، حيث أن هذا التعاون سيؤدي إلى انسجام تام بين الطرفين وتفهم كل منهم لطبيعة عمل الطرف الأخر مع تبادل المعلومات والآراء فيما بينهما ، وبالتالي الحصول على نتائج نهائية مرضية لكل منهما. لكن هذا التعاون لا يمكن أن يقوم وحده ولا بد من دعم الحكومة له وتسهيل وتوفير كل ما يلزم لذلك.

الفصل الرابع يقوم بترجمة الهيكل النظري إلى ستة أسئلة طرحت خلال فترة عمل المشروع ، كل سؤال منهم سيتم الإجابة عليه من الفصل الخامس وحتى العاشر وبشكل منفصل ، إلا أن القارئ سيلاحظ بأن هناك بعض التداخل فيما بينهم حيث كان من الصعب تجنب هذا أحيانا ، ومن ناحية أخرى فإن هذا التداخل يشير إلى أن تناول المشكلة تم بطريقة تدريجية ومرتبطة.

الفصل الخامس يدور حول طريقة إختيار موقع البحث المناسب والذي يجب على المزارعين فيه توفير كل شروط البحث المتفق عليها. تم الاتفاق على ثلاث مناطق ، كل منها تمثل نوعية محددة من مياه الصرف الصحي المعالجة وبشروط مسبقة مع المزارعين لجمع معلومات موثوق بها حول كيفية استخدامهم للمياه العادمة لإنتاج النبتة. كل ذلك يساعد في معرفة وتحديد مدى إمكانية استخدام مياه الصرف الصحي المعالجة في الأردن.

أما من ناحية مشاركة المزارعين في الثلاث مناطق المختلفة ، فقد كان المزارعين دائما راغبين في التعاون وتنفيذ كل ما يطلب منهم خلال فترة البحث كاملة ، كما كانوا حريصين على حضور جميع الاجتماعات وتزويدنا بالمعلومات والقراءات المطلوبة باستمرار. من ناحية أخرى فقد وجدت فجوة كبيرة بين كيفية أدراك العلماء لمشاكل

المزارعين وبين الطريقة التي يرونها هم أنفسهم ، مما جعلنا نعيد النظر في طريقة التعامل معهم حيث فضلنا أن نستخدم معهم أسلوب المحاورة بدلا من التلقين ، ونتعامل معهم كمصدر هام موثوق به للمعلومات.

الفصل السادس يعرض عواقب العمل مع المزارعين في حقولهم والتي يجب أن تأخذ في الحسبان قبل البدء في البحث. يصور هذا الفصل نموذج فرضي يظهر الخطوات التي يجب على المزارعين والباحثين القيام بها خلال عملية البحث كاملة. وقد قبل المزارعون هذا النموذج حيث أنهم شعروا بأنهم قد حصلوا على الدور المناسب فيه ، كما يقدم هذا الفصل خطة نموذجية حيث يتعلم الباحث والمزارع كيفية العمل سويا ، فوظيفة هذه الخطة تدريب المزارعون ليصبحوا المراقبين والمدراء الأساسيين في إدارة مزارعهم ، والباحثون ليثقوا ويعتمدوا على خبرات المزارعين.

الفصل السابع يوضح الخطوط العريضة لمدى ملائمة استخدام مياه الصرف الصحي المعالجة للري في منطقة البحث باستخدام متغيرات مختلفة مثل الموصلية الكهربائية للمياه ومجموع الصلب المذاب ونسبة امتزاز الصوديوم وسمومية الأيون ومجموع النيتروجين والفسفور والرقم الهيدروجيني ونوعية الأحياء المجهرية. وقد قيمت مدى صلاحية مياه الصرف المعالجة بناءا على مؤشرات منظمة الصحة العالمية ومنظمة الغذاء والزراعة. كما وتم التعرف على المخاطر المحتملة فيما يتعلق بالصحة العامة واستخدامها في الري. هذا وقد تم مراجعة القوانين الأردنية التي تحكم استخدام مياه الصرف الصحي المعالجة ووضع الخطوط العريضة للممارسات الإدارية الضرورية. كما يبين هذا الفصل التقييم الذي أجري على مياه الصرف الصحي المعالجة لغايات السماد وآثار الملوحة.

الفصل الثامن يوضح مصادر المعلومات الثلاث اللازمة لعمل دراسة المسح غير الرسمي وهي: الشركاء الإقليميين والمعلومات المتوفرة والملاحظات الميدانية. كما يوضح كيف أن المزارعين أصحاب المزارع الصغيرة عملوا على تصميم مزارعهم بشكل يسمح لهم باستخدام مياه الصرف الصحي المعالجة بطريقة سليمة وصحية ، وهذا النظام قائم على تقنية النماذج الأولية والمستخدمة بنجاح في معظم الدول الأوروبية. وفي هذا الفصل أيضا نبين الإجراءات اللازمة لإنشاء ما يلي:

- أهداف استخدام مياه الصرف الصحي المعالجة في المزارع والتي يجب أن نعمل على تحقيقها في المستقبل ، وقد تم في البداية تشخيص الوضع الحالي لاستخدام مياه الصرف الصحي المعالجة ، إضافة إلى تحديد المساهمة المطلوبة من النموذج الأولي في تحسين وضع استخدام مياه الصرف الصحي المعالجة على المدى البعيد في المنطقة ، وبالتالي يجب أن يتم التشخيص والتسلسل بالتفاعل مع العناصر الرئيسية ذات العلاقة باستخدام مياه الصرف الصحي المعالجة وبعد دراسة كافة المصادر المتوفرة والتقنية الزراعية والخبرات والمعرفة دراسة دقيقة.

- تحويل وتأهيل الأهداف لتصبح متغيرات ومعايير ملائمة. وهذا يعتمد على الدراسة والاختيار الدقيق للمعايير المتعلقة بالأهداف وبنظام الإنتاج والذي يعتمد على أهداف استخدام مياه الصرف الصحي المعالجة في الري. وقد تم إختيار المعايير اللازمة بحيث تكون متكاملة ولا يمكن الاستغناء عنها لتحقيق هدف أو عدة أهداف مترابطة. وبهذه الطريقة يمكن استخدام الأهداف المقاسة في النتائج المطلوبة لتقييم النتائج المتحققة من استخدام مياه الري في النماذج الأولية للري. توفر هذه الخطوة إحدى عشر متغير لاستخدام مياه الصرف المعالجة.

- تقنيات وأساليب الزراعة اللازمة مثل إدارة المياه والمواد المغذية ، والعمل على تحسين البنية الأساسية للمزرعة بحيث تكون أقرب ما يكون إلى الكمال والفعالية.

- النموذج الأولي النظري والذي يجب أن يؤمن حلقة الربط الداخلية للأساليب الجديدة مع كافة مستويات إنتاج المحاصيل الفيزيائية والبيولوجية والزراعية وسوق الانتاج على مستوى المزرعة ، ومن غير ذلك فإن الأهداف لن تتحقق وقد تتضرر استدامة وإنتاجية المحصول.

- تجربة النظام الزراعي الجديد في المزارع التجريبية.

قدمت النتائج الأولية لهذه الممارسة ، وقد أظهر تطبيق النماذج الأولية في الممارسة أن المزارعين المهتمين ما زالوا بحاجة إلى الكثير من التدريب والمعلومات. وأوضحت النتائج الأولية أن تصميمنا يحتاج إلى المزيد من التحسين من

خلال وضع إجراءات تدريجية لإعادة التجربة. كما وتبين النتائج مدى التأثر بالأساليب الزراعية التقليدية السابقة وقد تفهم المزارعون الكثير من الضرر الذي تلحقه أساليب التكنولوجيا الزراعية الحالية بالمصادر الطبيعية ذات العلاقة وبتوقعاتهم الزراعية المستقبلية. وللتخلص من الآثار السلبية لأساليب التكنولوجيا الزراعية الحالية ، فإن هذا يتطلب العديد من دورات إعادة التجربة.

يلخص الجزء الأخير من الدراسة العناصر الرئيسية لاستراتيجية تحسين النموذج .

الفصل التاسع يهتم في تحليل نقاط الضعف والقوة في إعادة تصميم المزارع ، ويقدم هذا الفصل أيضا تحليل **SWOT** الذي يدرس تطور أخر من نموذج مياه الصرف الصحي المعالجة في الأردن. نتائج هذا التحليل قد صيغت بطريقة تلائم أسلوب هذا البحث وتتناسب مع رغبة الحكومة وقطاع الخدمات. وقد استنتج من هذا الفصل بأن المزارعون يستطيعون تطوير أنفسهم فقط في حالة العمل على إدارة وتطوير نظام إنتاج زراعي معتمد ذات صفات ومعايير محدودة.

الفصل العاشر يعرض دور صناع القرار في استخدام مياه الصرف الصحي المعالجة بطريقة صحية وسليمة في الزراعة ، وكذلك يؤكد على التعاون بين منتجي ومستخدمي مياه الصرف الصحي المعالجة.

تنتهي الدراسة بخاتمة تتضمن توصية باستخدام مياه الصرف الصحي المعالجة في الزراعة بطرق سليمة.

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society expects farmers to solve problems concerning food quality and the environment. The tension between farmers and regional stakeholders thus increases.

8.2 Parameterisation of the general objective concerning the objective of income and profit.

8.3 Parameterisation of the general objectives in criteria theoretically presumed for regional stakeholders and farmers in zones A, B, and C. The dimensions given here are not exhaustive or limited to the ones that are indicated. Discussion between farmers and facilitator may result in many other relevant criteria or dimensions. However, for the present stage of their development, the presented criteria supports their interests. The final result is a matter of creativity: of local demands and of farmers’ experiences. Specifications should also be ranked according to group.

8.4 Ranking of the ten most important specified objectives for farmers in zone A, B, and C.

8.5 Provisional list of parameters according to the interest of regional stakeholders and farmers in the study area. This table shows that one parameter can quantify more than one objective, and indicates the number of participants interested in each parameter.

8.6 Provisional list of methods, used in the prototyping of treated sewagewater use in the study area, according to interests of participants. The participants selected only three farming methods because at this stage of the research were interested in water issues like nutrients in the treated sewagewater and quantities of irrigation water applied to the field. In later stages participants may identify other farming methods as new interests appear.

8.7 Farmers involved are considered to be those who want to create a new farming system. The left column shows the ranking of the ten most important targets which farmers are going to realise at their farms during the transition period of the project concerned. The column in the middle provides the quantification of the targets involved. The right column indicates relevant farming methods that might fulfil the targets. This table is just a model. Farmers, supported by the researcher, must provide the targets, the quantification and the methods.

8.8 Selected farms and crops

8.9 Cost of water and chemical fertilisers applied to the farms in zones A, B and C during the 1999-2000 and 2000-2001 growing seasons.

8.10 Average yields for Jordan compared with yields of all farms in zones A, B and C during the 1999-2000 and 2000-2001growing seasons and yields market prices o

8.11 Profitability comparison in all farms in zones A, B and C during the 1999-2000 and 2000-2001 growing seasons based on the cost of water and chemical fertilisers added.

9.1 Summary of the strength and weaknesses aspects of prototyping treated sewagewater use in irrigation according to farmers

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8.3 Crop production cost and income, profit and loss (BPA, 1988)

8.4 Changes in soil moisture levels (BPA, 1988)

8.5 Visualisation of a prototype of an integrated farming system (after Vereijken, 1995). The one on the left is for zones A and B and the one on the right for zone C. The numbers inside the circles indicate which farming method should be addressed at which moment. The links between circles and squares indicate which farming method best serves a parameter.

8.6 Mineral Nitrogen (N-NO3 plus N-NH4), Extractable Phosphorus (P) and Extractable Potassium (K) Soil Reserves at pilot farms in zone A, B and C at 2000-2001 growing season. Vertical columns indicates N-NO3 plus N-NH4, P and K values in soil at depth indicated in the legend in part per million (ppm) (1 ppm = 1 mg/kg). Horizontal columns indicate the desired ranges of N, P and K in soil in ppm. These values adapted from Garabet et al., 1996 (see Appendix 8.2).

8.7 Total Nitrogen (N), Phosphorus (P) and Potassium (K) Leaf Reserves at pilot farms in zone A, B and C at 2000-2001 growing season. Vertical columns indicates the NLR, PLR and KLR values in parts per million (ppm) (1 ppm – 1 mg/kg). Horizontal columns indicates the desired rangers of NLR, PLR and KLR adapted from various resources (see Appendix 8.1)

8.8 Macro-nutrient Balances in pilot farms in zone A, B en C in 2000-2001 growing season. Vertical columns indicate the Nitrogen (N), Phosphorus (P) and Potassium (K) balance. Horizontal lines indicates the desired ranges at this stage of the research.

8.9 Irrigation Index (II) at pilot farms in zones A, B and C in the 2000-2001 growing season. Vertical columns indicate the ratio between water used to water needed. Horizontal line indicates the desired range. These results accure from prototype management, not water quality.

8.10 Soil Salinity Index (SSI) at pilot farms in zones A, B and C in the 2000-2001 growing season. Vertical columns indicate soil salinity (Ece) ratio at the beginning of the growing season and at harvest. Horizontal line indicates the desired range. These results accrue from prototype management, not water quality.

8.11 Quality Production Index (QPI) at pilot farms in zones A, B and C for the 2000-2001 growing season. Vertical columns indicate the QPI in all farms. Horizontal line indicates the desired range. These results accrue from prototype management, not water quality

8.12 Net Surplus (NS) at pilot farms in zones A, B and C for the 2000-2001 growing season. These results accrue from prototype management, not water quality

8.13 Evaluation of the results obtained after one year of farming according to the indications obtained by creating a theoretical prototype for farms in Seil Al Zarqa and the Middle Jordan Valley. This evaluation gives a farmer a clear view on what he planned to do in combination with the results that he actually obtained in a certain year. For example, from this evaluation we may conclude that the farmer still has a long way to go, but also that his management of the completed production year was partly successful. He makes himself aware of everything he still has to do through the coming year. The farmer thus learns from the consequences of certain decisions. He learns effectively. This helps him learn from his farm and from his mistakes each year.

9.1 SWOT analysis of the prototypes developed during the project in question. A,B,C and D are quadrants that each reflect developmental potential for prototypes. The difference between A and D is that in A the farmer was the point of impact. He learned to learn from his mistakes and stimulated the creation of a farm with better production conditions. He could do so without help of government or sector. He just needed coaching. In D the surroundings of the farm (government, market, trade organisation, sector) was the point of impact. Once the farmer feels himself stimulated by his surroundings he starts to understand that he must change as long as he wants to continue his farm.

9.2 shows the movements that could be made by prototypes in the course of time to strengthen existing prototypes and get more prototypes in the research area (topographical designation) up and running. The arrow from C to A indicates the movement made during the research in question. The dotted arrow from A to B indicates what the prototypes in our research area should experience as a result of environmental stimuli. The movement from C to D represents what the government could ‘enforce.’ Farmers that do not have a good starting position can be encouraged (systems of reward) to use treated sewagewater permanently.

9.3 The triangle represents the Jordanian farms in the research area of the project in question. The government stimulates a prototype via the following route: redesign the basic cycles of farms (soil and crop protection cycles), and subsequently develop demonstration farms that link convincing evidence to entrepreneurial patterns of behaviour. Following this, develop certification and labelling systems and, finally, allow the producer to operate freely in his respective market. The arrow indicates that the government must help both in terms of increasing the number of prototypes and in terms of rooting these firmly, in order that they may experience sustained growth from situation C to B.

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Abbreviations

AESW	Animal Exposure to Sewagewater
BOD	Biological Oxygen Demand
CLIS	Council of Leading Islamic Scholars
COD	Chemical Oxygen Demand
EESW	Environmental Exposure to Sewagewater
ESP	Exchangeable Sodium Percentage
FAO	United Nations Food and Agriculture Organisation
FSO	Farm Structure Optimisation
HESW	Human Exposure to Sewagewater
ICRA	International Centre for development-oriented Research in Agriculture
II	Irrigation Index
IUCN	International Union for Conservation of Nature and Natural Resources
KAC	King Abdulah Canal
KLR	Potassium Leaf Reserves
KSR	Potassium Soil Reserves
KTD	King Talal Dam
LR	Leaf Reserves
MB	Micro-nutrients Balance
MBAS	Methylene Blue Active Substances
MCM	Million Cubic Metre
MLR	Macro-nutrient Reserves
MPN	Most Probable Number
MSR	Macro-nutrient Reserves
NGO's	Non-Governmental Organisations
NLR	Nitrogen Leaf Reserves
NM	Nutrient Management
NS	Net Surplus
NSR	Nitrogen Soil Reserves
OMB	Organic Matter Balance
OMC	Organic Matter Content
PLR	Phosphorus Leaf Reserves
PSR	Phosphorus Soil Reserves
QPI	Quality Production Index
RSS	Royal Scientific Society

SAR	Sodium Adsorption Ratio
SS	Suspended Solid
SSI	Soil Salinity Index
SWAP	Soil-Water-Atmosphere-Plant
SWR	Slight to Moderate Restriction
TDS	Total Dissolved Solid
TFCC	Total Faecal Coliform Count
THMS	Trihalomethanes
T-N	Total Nitrogen
ToT	Transfer of Technology
T-P	Total Phosphorus
TSS	Total Suspended Solid
UNCED	United Nations Conference on Environment and Development
WHO	United Nations World Health Organisation
WM	Water Management

About the author

Mohammad Duqqah was born in Amman, Jordan, on July 12, 1964. In July 1986 he obtained his *B.Sc.* in *Soil and Irrigation* from the faculty of agriculture at Jordan University. Subsequently, he gained experience through working in private companies and with farmers in Jordan, providing services and exchanging knowledge.

In 1996 he obtained his *M.Sc.* in *Irrigation Engineering* from The Institute of Irrigation Studies, Department of Civil Engineering and Environmental Science at Southampton University, the UK. The study involved technical as well as socio-economic subjects. After this study he was appointed as research assistant at The Water and Environment Research and Study Centre at Jordan University. During his work at the centre he gained experience in subjects related to water and the environment. He assisted researchers in many projects concerning irrigation systems and management, and low cost technologies for sewage treatment and use.

In June 1998, he started preparation for his *Ph.D.* research at Wageningen University, the Netherlands. The subject of the research was the use of treated sewagewater in irrigated agriculture.