Water Re-Use

Sustainable waste water reuse technologies for irrigated land in NIS and southern European states

Project no. 516731

WATER REUSE

Sustainable waste water recycling technologies for irrigated land in Nis and Southern European States

INCO-2003-D1 Environmental protection

DELIVERABLE 26: Report on comparative results of tested water saving techniques, with respect to mainly physical factors at local and regional level, including ranking of techniques for a range of environmental conditions

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Authors:
Simone Verzandvoort (Alterra, WUR), Demie Moore (Alterra, WUR) , Erik van den Elsen (Alterra, WUR), Fuensanta Garcia Orenes (University Miguel Hernandéz, Spain), Jorge Solera Mataíx (University Miguel Hernandéz, Spain), Alicia Morugán (University Miguel Hernandéz, Spain), Vasilis Diamantis (Democritus University of Thrace, Greece), Tatyana Laktionova (Institute for Soil Science and Agrochemistry Research, Ukraine), VitalyiMedvedev (Institute for Soil Science and Agrochemistry Research, Ukraine), Anatoly Zeiliguer (Moscow State University of Environmental Engineering), Olga Ermolaeva (Moscow State University of Environmental Engineering)

Project coordinator: Prof. Dr. Coen Ritsema, ALTERRA

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PU	Public	**PU**
PP	Restricted to other programme participants (including the Commission Services)	
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1 Introduction

In irrigated areas in the New Independent States (NIS) and southern European States, inefficient use of conventional water resources occurs through incomplete wetting of soils, which causes accelerated runoff and preferential flow, and also through excessive evaporation associated with unhindered capillary rise. Furthermore, a largely unexploited potential exists to save conventional irrigation water by supplementation with organic-rich waste water, which, if used appropriately, can also lead to improvements to soil physical properties and soil nutrient and organic matter content (e.g. Lazarova and Asano, 2005). The overall objective of the Water Reuse project was to develop new and to advance existing sustainable water saving strategies in the NIS and Mediterranean states focusing on largely unexploited opportunities for (a) water saving, and (b) using organic-rich wastewater as a non-conventional water resource on irrigated land. In particular, the project aimed to (a) reduce irrigation water losses by developing, evaluating and promoting techniques that improve the wetting properties of soils, and (b) investigate the use of organic-rich waste water as a non-conventional water resource in irrigation and, in addition, as a tool in improving soil physical properties and soil nutrient and organic matter content.

This report discusses the findings of the Water Reuse Project in relationship to biophysical environmental conditions. The objective is to identify where the water saving strategies tested on plot scale, may be applicable or not on a field and/or regional scale, and why – in terms of the land conditions, independent of socio-cultural-economic factors.

The report is structured as follows. **Chapter 2** gives a short biophysical description of the study areas. **Chapter 3** outlines major problems in sustainable land and water management motivating the introduction of water saving strategies in the studied regions. **Chapter 4** sketches the biophysical conditions where the water saving strategies were tested, and the importance of each condition for the applicability of the water saving strategies. Finally, **Chapter 5** describes the environmental (biophysical) conditions under which the strategies are likely and not likely to be effective, and suggests locations in the participating countries, Europe and the world where the environmental conditions may exist for successful use of the water saving strategie(s) tested.

Sunset on Volga River. Photo: Anatoly Zeiliguer

2 Short biophysical description of study areas

2.1 Alicante province, Spain

Alicante province is located in the Southeast of Spain, and is one of the three provinces that constitute the Valencian Community, next to Valencia and Castellon de la Plana. The province of Alicante is formed by a total of 8 sub-regions and has a total area of 5883 km^2 corresponding to 1.16 % of the total area of Spain.

2.1.1 Climate

Due to the geographical situation of Alicante temperate-humid, semiarid, and dry climates interact in the province, causing a high incidence of heatstroke. Alicante can be assigned to the typical Mediterranean climatic zone. Winters are smooth; values lower than 0º C are not frequent in coast zones and in internal zones oscillate among 4º and 6º C. There is a scarcity of rain in the southern zone, with two annual rainfall maxima and minimum rainfall in July and August, when the rainfall barely surpasses 20 mm. This limits agricultural activities in certain parts of the province.

The provincial orography provides an altitudinal contrast between internal areas and coastal zones and conditions the spatial distribution of rainfall and temperatures. The most important rainfalls are produced in the northern part of the province, with annual values over 1000 mm joined to periods of intense rainfalls. Intense rainfall occurs more frequently in autumn. These events are characterized for their great spatial and temporary irregularity.
Zones receiving more than 200 mm of rainfall during an event may be located next to zones receiving very little rainfall. Runoff events due to intense rainfall are characteristic of the Spanish Mediterranean environment.

2.1.2 Soils and land use

Forest, agricultural, industrial and urban areas are the main land uses in the region. In the study area the main land use is the agricultural, especially that dedicated to the grape. The soils in the region are very diverse, a common situation in the Mediterranean. The soil of the experimental site (Calcareous Regosol) is however one of the most common soil types of the province the region.

Figure 2-1 Golf course, Alicante, Spain. Source: UMH progress report for the Waterreuse project, year 1.

Figure 2-2 Agricultural land on a sandy, calcareous soil. Biar, Alicante. Photo: UMH ©.

Figure 2-3 Location of the experimental field site of the Water Reuse project in Alicante, Spain. Source: UMH ©.

Figure 2-4 Experimental field site of the Water Reuse project in Alicante, Spain. Source: UMH ©.

2.1.3 Social and economic aspects

Although the province has showed a continuous population growth during the 20th century, during the first 50 years, this was less than in the rest of Spain due to outmigration to the French colonies of North Africa. Nevertheless, since1960 there was an increase of population growth. This fact caused a very significant increase of the relevance of the province in the country. At present, with 3.93% of the Spanish population, the province of Alicante is in the best economic and demographic moment of its history, being already one of the most densely populated provinces. Immigration has significantly contributed to this growth.

The economic productivity of Alicante is important compared to other provinces. The most productive sectors include tourism, services (mainly in the capital) and industry (textile, footwear, toy industry, marble industry). Traditional activities, such as agriculture, are in a clear backward movement, although the cultivation of citrus, vegetables and grapevine is still important.

2.1.4 Waste water use

The shortage of natural water resources in arid and semiarid zones in the Mediterranean regions affects all water users. Fresh water is scarce in these regions due to a large consumptive domestic use by the growing population with changing lifestyles, the flourishing tourism sector and the agricultural sector in particular (Figure 2-1, Figure 2-2). Irrigated agriculture is a vital component of the agricultural sector in Spain. Even if it just occupies about 20% of total crop area, it produces 60% of the total Gross Value Added (GVA) of this sector (MIMAM, 2007). The economic productivity (€/ha) in irrigated agriculture in Spain is about five times higher than that of rainfed agriculture (Plan Nacional de Regadios, 2009). A biophysical cause of the water scarcity in the province of Alicante is the low rainfall and its irregular distribution over the year. In combination with the limited resources of fresh water and the afore mentioned demand for fresh water, this leads to groundwater depletion.

This context motivates the reuse of wastewater in agriculture as a logical option to be considered for the sustainable management of water resources. Wastewater has been used for irrigation since ancient times by the Greek and Roman civilizations to take advantage of the nutrients carried in the water and to avoid the contamination of rivers. With the invention of new technologies for water treatment and irrigation systems the use of wastewater in agriculture has experienced a new impetus. In Alicante province, the number of waste water treatment plants has risen from 121 in 2001 to 140 in 2005, and the volumes of available treated wastewater for agriculture have accordingly increased.

2.2 Saratov Region, Russia

The field experimental site for the Water Reuse project in Saratov region is located in the southwest of Russia, in the northern part of the Marks District, in the Saratov Region. This area is part of the Great Russian Plain, on the eastern bank of the lower part of the Volga River (Figure 2-5).

Figure 2-5 Location of Water Reuse study area in Saratov Region, Russia. Source: Zeiliguer and Ermolaeva (2009). Yellow area in the upper picture indicates location of Saratov Region.

2.2.1 Climate

The Marksovsky district has a moderately continental climate. The summer is quite long and hot, lasting from May through September, winter lasts from December through February. The difference between maximum winter and summer temperatures is 85°C, the difference between average temperatures of winter and summer is 35°C. The annual precipitation varies from 391 to 435 mm (Fig. 4). The relative air humidity never exceeds 80%, during summertime it averages about 60%. A blanket of snow settles on the region in the beginning of December and melts away during the last ten days of March (Figure 2-6). The average maximum snowfall is 28.5 cm in the forested plains, 26.5 cm in the plains. In April the water storage in the upper 100cm layer of soil reaches 80-150 mm (Zeiliguer and Ermolaeva, 2009).

Figure 2-6 Snow covered field in Saratov region. Source: MSUEE (2009).

2.2.2 Soils and land use

The irrigated lands are located mainly on the right bank of the Volga River valley at one of five river corridor terraces. This territory is characterized by the most favourable soil and hydro-geological conditions and is suitable for irrigated farming. Fertile automorphic chestnut soils have been formed on the terraces. As a rule, the ground water is fresh, slightly alkaline; sometimes it contains salts but their concentration is very low. The ground water table was mainly located at a depth of 5-7 m and deeper. The unsaturated zone has a two-layer structure: a low penetration upper layer (loamy soil) and a water bearing lower horizon (sand or loamy sand) (Zeiliguer and Ermolaeva, 2009).

A thick layer of alluvial sediments (up to 40-60cm) contains a fresh water-bearing horizon. Therefore, the first industrial irrigation systems have been built here in the 1960s. In spite of the relatively high natural drainage, the development of irrigation has caused the groundwater table to rise and water-logging conditions on the adjacent areas. This was followed by dissolution of salt in the upper unsaturated ground layers and by a rise of ground water with higher salt concentrations into the root zone with a negative impact on soil fertility. Water-logging occurs first at the lower terraces above flood lands because of both infiltration of irrigation water and subsurface inflow from the upper terraces.

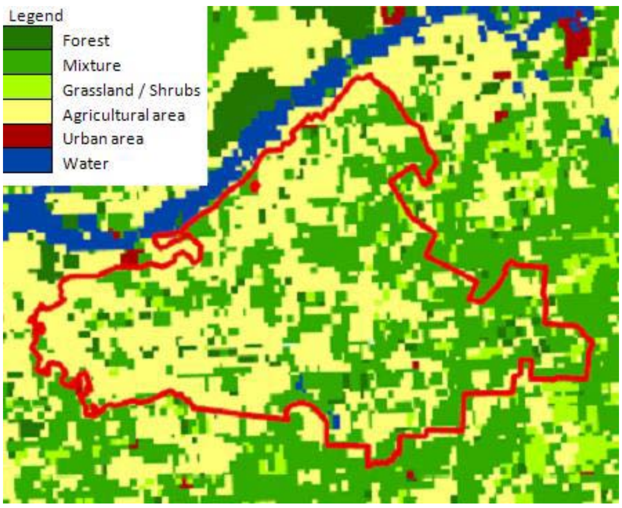

Figure 2-7 Land use map of the Marks District, Saratov, Russian Federation. Source: Zeiliguer and Ermolaeva (2009). For the location of the Marks District, see Figure 2-5.

The Marks District is an area of intensive agricultural production. Most people in the region are working in the agricultural sector. Arable lands are covering 195,400 ha of the Marks District. The crops constitute of around 50% cereals, 1% vegetables and potatoes, 20% technical plants and 20% forage. The number of livestock in the Marks district is 32,300 heads, of which 13,000 cows, 26,600 pigs, 15,800 sheep and 276,000 birds. The field experiments i the Water Reuse project were done in alfalfa and corn fields (Figure 2-8).

Figure 2-8 Corn (left) and alfalfa fields for field trials in Water Reuse project. Source: MSUEE (2009).

2.2.3 Water resources and irrigation history

Water resources are pivotal for the agriculture in this region. The region has ample water resources. The average long term river flow from sources located within the Saratov Region's boundaries is 264.8 km^3/year. Estimated resources of underground water use are 1.98 km^3/year. However, the Volga River has multiple uses, like for hydropower generation, irrigation, navigation and fishery. Therefore water resources should be managed in an adequate manner, taking into account all water users as well as the ecology of the river system.

Every irrigated hectare of land in Marks District gives about 40 - 45 centers of forage. Around 75% of the forage yield is provided by irrigated agriculture. However, irrigated land requires financial expenditures for repairing and exploitation of pumping stations, canals and other structures. The main cause of the decreasing area for irrigation is the bad condition of structures and ageing of the irrigation network. The main canals and distribution network of irrigation system are in exploitation for more than 30 years, but these structures already finished their resources. There is a need for quite a big financial support to repair or replace these structures. As these structures belong to state, the financial problem is imposed on governmental services (Zeilguer and Ermolaeva, 2009).

Figure 2-9 Pivotal sprinkler irrigation system, Saratov region, Russian Federation. Source: MSUEE (2009).

A major land degradation problem in this area is caused mainly by the long time irrigation system used since its construction in the 1960s, which provoked a ground water table rise due to over application of irrigation water from a minimal depth of 5-7 meters prior to the irrigation systems, to the active root zone at present (Pankova, 1993). As a consequence, the rising ground water provokes (1) water logging of irrigated and surrounding areas causing a change of soil water regime from semi-arid to semi-humid, (2) a secondary soil salinization due to dissolution of salt crystals held in the ground layers of the vadose zone and raising them to the upper root zone, which creates toxic conditions for plants and augments a soil water osmotic pressure leading to diminished water availability for plants water in soil, (3) decreasing soil organic matter content due to leaching, which leads to soil compaction, damage of soil structure, worsening hydraulic conductivity & water retention capacity and other soil parameters. From the land users' point of view a high groundwater level, a non-uniform pattern of soil fertility and extensive weed growth are consequences of former extended irrigation that is still maintained in some areas (Zeiliguer and Ermolaeva, 2009).

An irrigation system called "Komsomolsky" was constructed at the territory of the Marks District, pumping water from Volga River (Fig. 9). However, from the beginning (1960) this system was designed for the use of industrial irrigation with localized pivotal type of sprinkler equipment like Valley (for irrigation at once about 50-70 ha) by agri-industrial collective farms to produce crops for farm animals (Figure 2-9). Actually at the market conditions in this region there are many farmers looking to diversify agricultural irrigated production by growing legumes. Unfortunately, the existing irrigation technology and equipment (water supply canals and huge pivot sprinkler systems with pressured water) is not compatible with the new mobile irrigation method for small plots. Therefore many new farmers use an old furrow irrigation system (exported from Central Asia) in the fields located near existing water supply canals. This irrigation system in the context of local conditions (soil types and ground water with accumulated salts) is very dangerous in terms of soil degradation/salinization as well as erosion.

Figure 2-10 Water erosion induced by an over-application of irrigation water. Photo: Anatoly Zeiliguer.

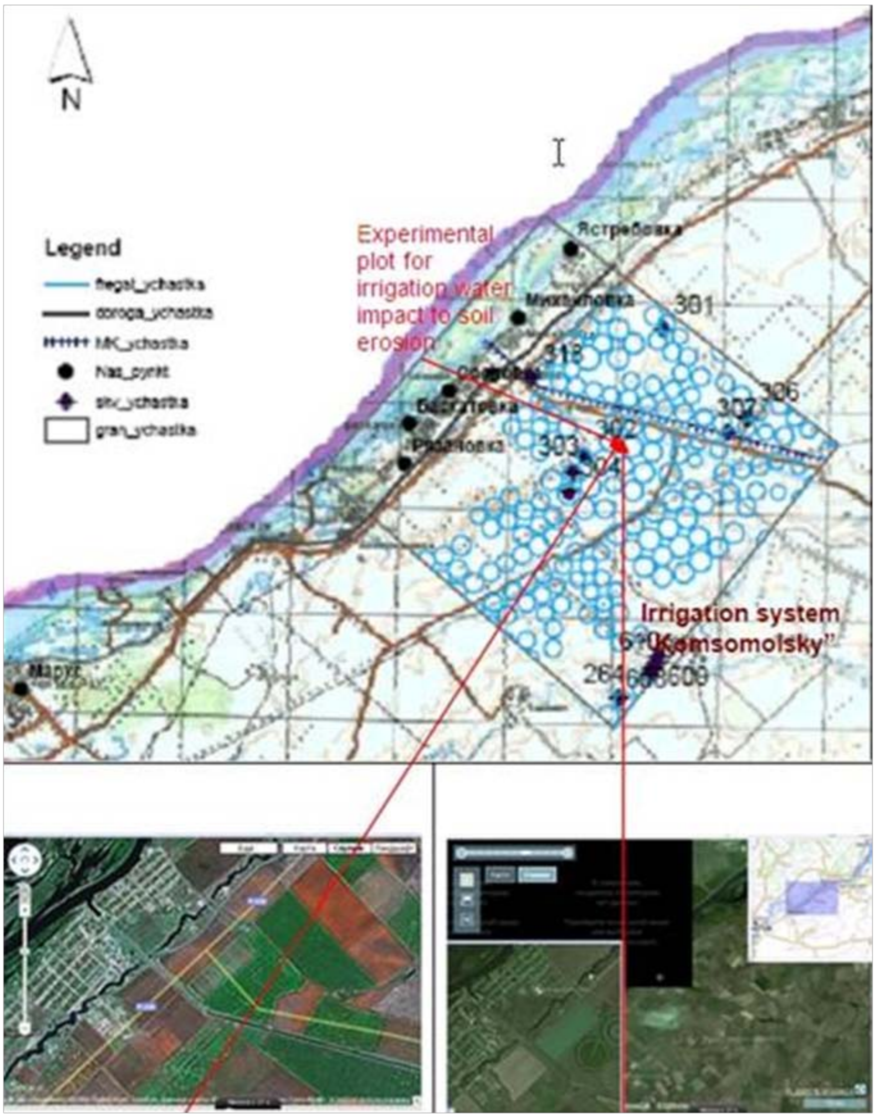

Figure 2-11 Komsomolsky irrigation system. Source: Zeiliguer and Ermolaeva (2009).

2.3 Kharkiv region, Ukraine

The field experimental stations employed for the Water Reuse project in Ukraine are located in the Kharkiv region, Kharkiv District, v. Korotych on almost plain land. The region is located in east part of Ukraine (Figure 2-14).

2.3.1 Climate

The area belongs to the Forest Steppe zone, and is characterized by a moderately moist, warm climate, with 470-515 mm of annual rainfall. Hydrothermal coefficients range from 1.3-1.0,$\Sigma > 10^0$ C – 2500-2900; Average annual temperature is 6.0-7.0° C. The absolute minimum air temperature is –34°C, and the absolute maximum + 35° C. Warm period is 290 days, vegetation period is 165-198 days.

2.3.2 Soils and land use

The study area is part of the Dniper-Donetzk lowland in the Eastern-European plain. This belongs to the Southern Left Bank of Forest Steppe zone. The soil type of the experimental plot isHaplic Chernozem heavy loam (code 12 in Figure 2-12), formed in a loess substrate. The groundwater is deep (>10 m). Humus content in soil profile is from 4.5% (H horizon) to 1.6% (Hp). The general composition of the soil profile is:

- humus horizon (H) - 0-50 cm
- 1st transition horizon (Hp) - 51-80 cm
- 2nd transition horizon (HP) - 81-115 cm
- loess (P) - > 115 cm.

The Kharkiv region is chracterised by the occurrence of different types of Chernozems (codes 8 to 21 in Figure 2-12).

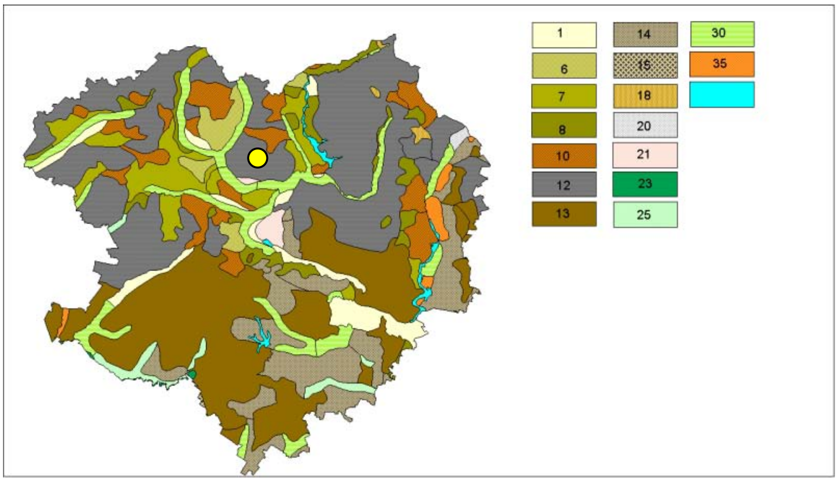

Figure 2-12 Soil map of Kharkiv region, scale 1:1500000 (Source: Atlas of Ukrainian soil properties maps, CD.- T.Laktionova, V.Medvedev et al., 2006, Ukr.)

The main crops grown in irrigated agriculture are corn and wheat (spring and winter)

Figure 2-13) sunflower and vegetables. The experimental plot was set-up in a fallow land, which was tilled before the start of the experiment.

Figure 2-13 Experimental field plot for the Water Reuse project in Kharkiv region. Spring wheat in a mulched surface. Source: ISSAR (2009).

2.3.3 Use of wastewater for irrigation

In Ukraine there is a long record of positive experiences in using wastewater for irrigation and fertilization in agriculture. Nevertheless, currently only 5% of wastewater produced in Ukraine is used for irrigation, while 16% would be suitable according to national standards (Salo et al., 1991). Due to the economic crises following the transition from the Soviet regime to a market economy, the material and financial resources to maintain irrigation systems have declined, and the awareness of wastewater as a resource for irrigation has decreased.

The region has insufficient rainfall for rainfed agriculture, and therefore field cultures require irrigation. At the same time fresh water resources are insufficient for irrigated agriculture. The use of wastewater for irrigation provides a logical water saving strategy. The wastewater used in the irrigation experiments was derived from municipal waste water from Kharkiv and Mariupol. These wastewater types are most widespread, are currently used for irrigation in the region, and have scope for wider application in the future.

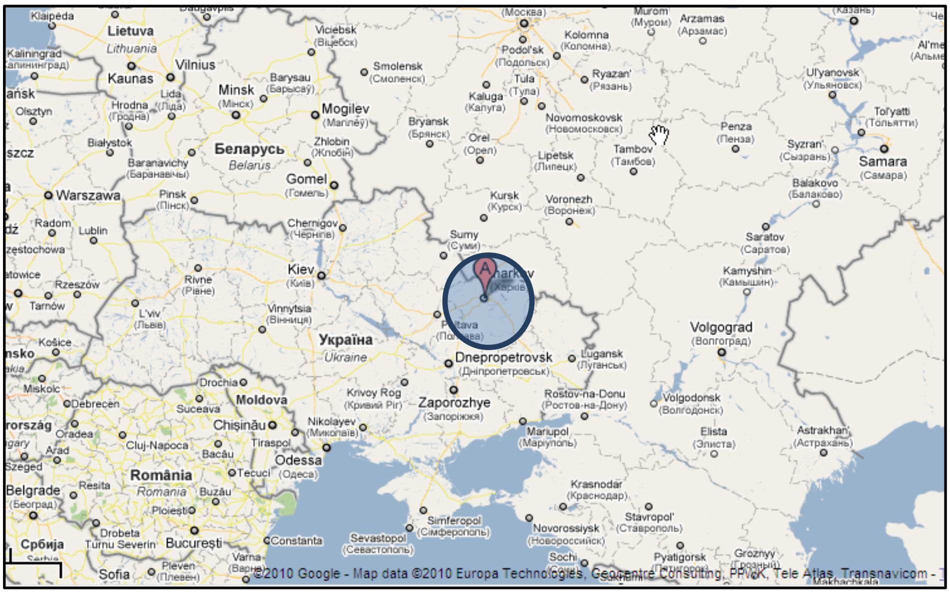

Figure 2-14 Location of Kharkiv regionand city (marker) in Ukraine. Adapted from Google Maps.

2.4 Maggana region, Greece

The study area in Greece is situated in the East Nestos river delta (Prefecture of Xanthi) at a distance of 1.7 km from the coast. The area is located in the coastal plain. The plain region of Maggana is part of the Nestos River and Laspias stream alluvial field, forming a large alluvial fan which extends south to the coastline of Thracean Sea (Figure 2-15).

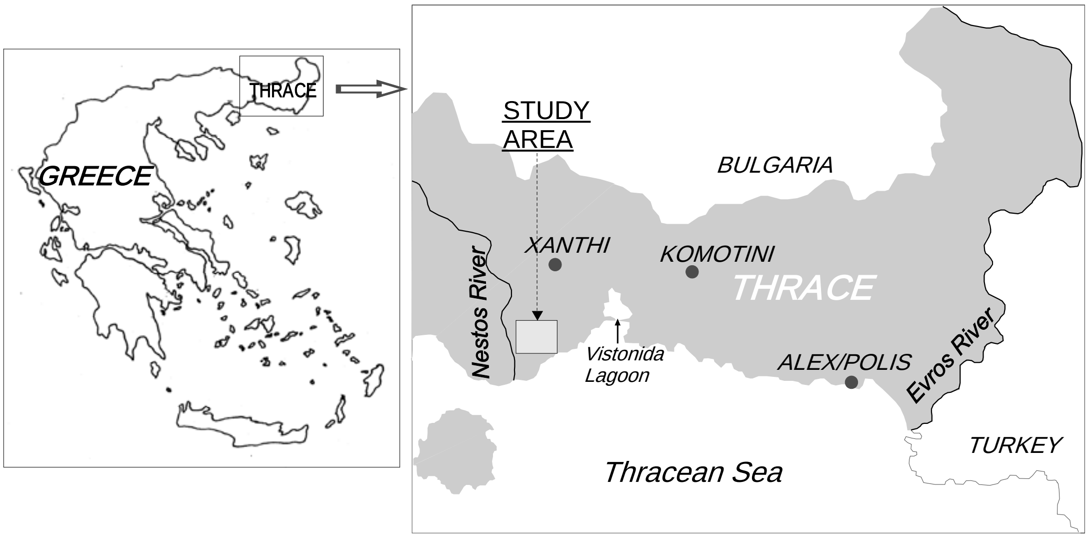

Figure 2-15 Location of the study area for the Water Reuse project in Maggana region, Greece. Rectangle indicates the location of the study area. Source: DUTH (2005).

Figure 2-16 Location of Nestos River Delta and Maggana study area. Source: DUTH (2009).

2.4.1 Climate

Greece is characterized be a severe water imbalance particularly in the summer months, due to low precipitation and, at the same time, increased demands for irrigation and water use due to tourism. The climate of Greece is sub-humid Mediterranean with humid and relative cold winters and dry and warm summers with an average rainfall of 870 mm/year. Annual rainfall ranges from 300 to 500 mm in the southeast of Greece and from 800 to 1200 mm in the north-western plains of the mainland, while in some mountainous areas it may be above 2000 mm. Thelarge climatologically differences are due to the complex vertical and horizontal distribution of the mountains and the great number of islands.

In the experimental coastal region, the climate is semi-humid Mediterranean type, and the average annual precipitation is 550 mm. Maximum temperature is 38°C during July and August and minimum temperature -5°C during December to February. The average daily humidity ranges from maximum 100% during winter to minimum 40% during summer.

2.4.2 Soils and land use

There is a variety of soil types in the prefecture of Xanthi from clay to sand. Most abundant soil types are sandy, sandy clay loam and sandy and silty loam (Table 1). The main crop types and area farmed, based on the Statistical Service of Greece, are shown in Table 2.

Table 2-1Main soil types in the Prefecture of Xanthi, Greece. Source: Democritus University of Thrace, Greece.

Soil type	Percentage of agricultural land (%)	Soil type	Percentage of agricultural land (%)
Sand	22.0	Clay loam	4.4
Pegmatic sand	2.2	Sandy clay loam	20.2
Loamy sand	9.0	Sandy clay	6.5
Sandy loam	13.4	Loamy & blocky peds	2.2
Silty loam	13.4	Metamorphic rocks	2.2

Table 2-2 Agricultural farmland, crops by categories and fallow land during the year 2004 (in 1000 m^2). Source: Democritus University of Thrace, Greece.

Prefecture	Xanthi
Land area farmed as a whole	450.303
Total farm land plus fallow land	453.783
Cultivated land (land ploughed)	403.708
Land used for vegetable farming	22.831
Orchards	
Total	10.461
Olive groves	4.292
Vineyards – currant vineyards	551
Fallow land (1-5 yr)	16.232

2.4.3 Hydrogeological setting and irrigation practice

The study area is extended within a recent sedimentary delta environment of a thickness of some tens of meters formed by the Nestos deposits. The alterations of sand, clay and silt layering deposits, which resulted from a wide range of structural and depositional processes, produced a heterogeneous geological environment. The presence of organic clay at some locations due to the Delta marshes is also important. The topsoil in the flood plain consists of fine grained sediment.

Soil surface elevation is 1.8 m above mean sea level and the groundwater table is near soil surface during in the winter and spring seasons.

Laspias stream is located across the eastern side of the study area where the degraded industrial and sewage treatment effluents are discharged. Northerly, at a distance of about 2 km, a drainage trench is located, which after draining the northerly irrigated land, conveys water into the Laspias stream.

Irrigation water is pumped from groundwater. Continuous pumping for irrigation has resulted in sea water intrusion into the coastal aquifers, and soil salinization and alkalinization. Two distinct hydrogeological systems exist within the alluvial deposits of the wider study area:

- The shallow system, consisting of phreatic and mostly of semi-confined aquifers extended down to a depth of approximately 30 m. Natural recharge to this system originates mostly from the infiltration of rainfall and less from the stream percolation of the north hilly area. During the last decade, a great amount of small diameter shallow wells (up to 15 m depth) were pumping water out of the system. Nowadays, only few of them are operated, whilst many of the other shallow wells have been replaced by deeper wells (up to 50 m depth), like in Dekarchon area.

- The deeper system, consisting of confined aquifers extended to a depth of at least 190 m. Natural recharge to this system comes to a great extent from river Nestos percolation through buried old stream beds, and from the lateral groundwater inflows coming from the adjacent hydrogeological basinof Vistonida Lake .

Figure 2-17 Soil salinity in the Nestos Delta, Greece. Photo: I. Giougkis.

3 Major problems in sustainable land and water management motivating water saving strategies

3.1 Major land use problems related to soil, water, and land management

The major problems in sustainable land and water management motivating the introduction of water saving strategies in the studied regions were stated by the research teams and by consultation of land users. They were summarized as 'land use problems' based on FAO's definition of 'land' as including soil and terrain forms, attributes of the near-surface climate, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.) (FAO/UNEP, 1997).

A synoptic overview of the problems mentioned by both groups in all regions is given in

Figure 3-2, Figure 3-3 and Figure 3-4. This shows that salinization is the most frequently mentioned problem related to soil, the scarcity of fresh water is the most frequently mentioned water related problem, and low crop productivity is the most frequently mentioned land management problem.

Figure 3-1 Salinization of soils. Example from Maggana region, Greece. Source: DUTH (2009).

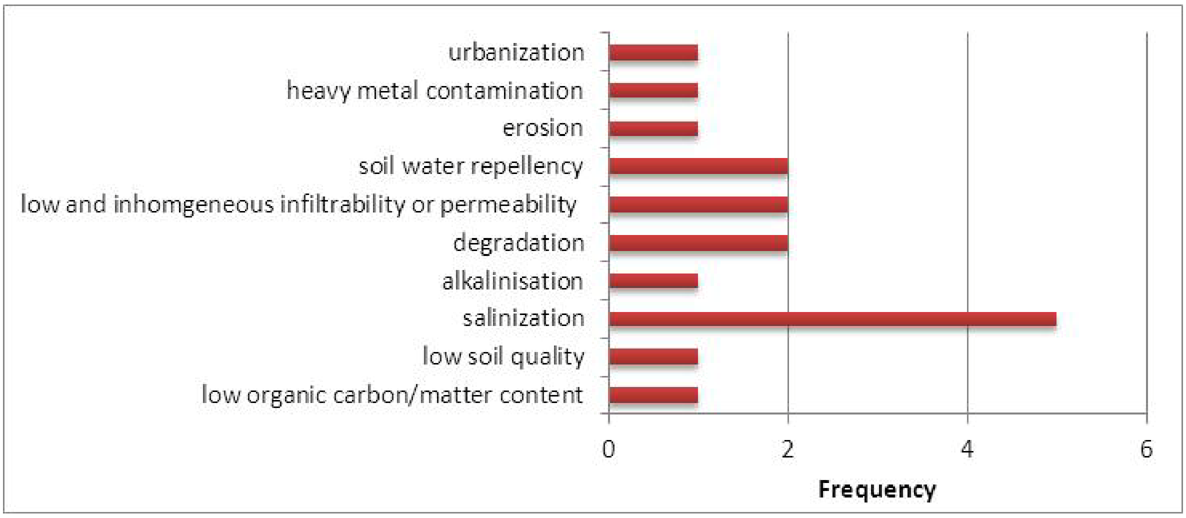

Figure 3-2 Overview of soil related problems in studied regions mentioned by researchers and land users.

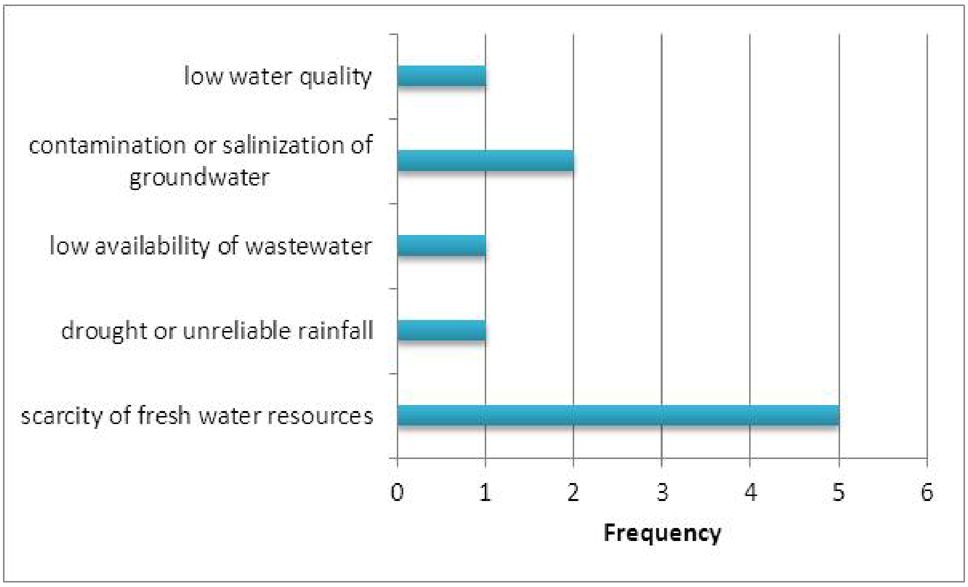

Figure 3-3 Overview of water related problems in studied regions mentioned by researchers and land users.

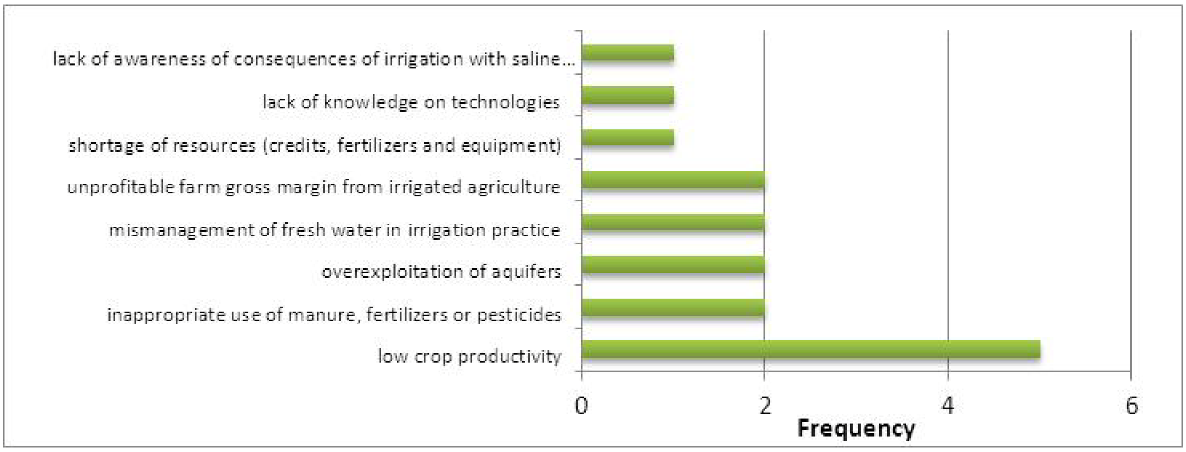

Figure 3-4 Overview of problems related to land management in studied regions mentioned by researchers and land users.

There is no consistent pattern in the difference between the mentioning of land use problems by the researchers and land users. In all regions except the Maggana region in Greece, the researchers mention more land use related problems than land users. Most differences were observed among the problems mentioned with regard to land management. These include problems that would indeed not be expected to be mentioned by land users, referring to the inappropriate use of resources and water and to the lack of knowledge on technologies or the consequences of land or water management.

3.1.1 Spain

For the Spanish region, according to the researchers soil related problems include the low organic carbon content, salinity, erosion, degradation, contamination with heavy metals, and urbanization. Water related problems in the Alicante region include the scarcity of fresh water, contamination of groundwater, and the low quality of surface and groundwater. Problems related to land management include the inappropriate use of fertilizers and manure, low crop productivity.

According to the land users, low soil quality, soil salinization and degradation constitute the most important soil related problems. With regard to water, land users mention the scarcity of fresh water and the low availability of wastewater as problems. Land management problems include the low crop productivity and overexploitation of aquifers.

Problems dealing with soil fertility (low soil quality, low organic matter or carbon contents) were uniquely mentioned for the Spanish region. This also applied to problems dealing with soil degradation and soil threats (erosion, heavy metal contamination, urbanization). Also, the overexploitation of aquifers was uniquely mentioned as a land use problem for the Spanish region.

3.1.2 Russia

From the researchers' point of view soil salinization and soil alkalinisation constitute one of the major soil related land use problems for the irrigated land in the Saratov region. In Soviet times widespread irrigation provoked the rising of groundwater levels, inducing secondary soil salinization and alkalinization (in case the salts dominantly consist of sodium carbonates) in the unsaturated zone of the soils (Gabchenko, 2008).

The capillary rise of dissolved salts to the root zone causes toxic conditions for plants due to the increase of the osmotic pressure gradient in the soil. This results in the diminished availability of water for plants. Another negative effect of soil salinization and alkalinisation is the development of spots with low infiltrability or permeability for rainfall and irrigation water.

The low and inhomogeneous permeability of soils is mentioned as a major problem in agricultural fields irrigated by pivotal sprinkler installations by both researchers and land users. The low permeability on local elevations runoff accumulates temporarily in local depressions, where preferential flow takes place. Land users report that at the same time significant parts of irrigated fields are too dry and too wet. By leaching from the root zone, the percolated water is often lost for crops to the groundwater, with consequent rising of the groundwater level with included salts. This type of secondary salinization is attributed to inappropriate irrigation techniques. However, the researchers report that land users are not aware of the fact that salinization is caused by the rise of the groundwater table, which in turn is caused by the inappropriate application of irrigation water.

Among the problems related to land management the researchers mention the absence of a stimulus to land users to modernize irrigation techniques and to increase the efficiency of irrigation in agriculture. This relates to the regional policy, which subsidizes the energy used for the transport of water from the Volga River to fields.

As a result of the inhomogeneous permeability of fields, land users in Saratov region experience similar patterns in crop productivity, with sub-optimal yields on spots which are too dry and too wet. Overall, the average yield from fields is sub-optimal.

Land users also experience the scarcity of fresh water resources as a major land use problem, which is even more problematic due to the large distances from fields to water resources for irrigation (usually rivers) (Figure 3-5). Land users turn to snow melt water from small ponds as a resource of irrigation water. With regard to land management, the cost-benefit ratio of irrigated agriculture is unfavourable for land users, with costs of water supply and operational costs largely surpassing revenues from crop yields. Without the regional subsidies on energy used for irrigation, many agricultural enterprises would go bankrupt.

Figure 3-5 Empty water supply canal in Saratov Region, Russian Federation. Photo: Anatoly Zeiliguer.

3.1.3 Ukraine

From the research team's point of view there are no major soil related problems hampering agricultural land use in Kharkiv region. The physical soil properties and nutrient availability are favourable. This is also experienced by the land users.

The unreliability of rainfall and the incidence of drought in the period April-June however may hamper agricultural land use. Land users have adapted to this phenomenon in several ways. Soil moisture cumulated in the soil during autumn and winter is conserved by minimizing the number and depth of soil tillage in the spring. When soil moisture contents are low, and not too much weed is present, farmers usually only perform harrowing and tillage to small depths. Other agro-technological methods to conserve soil moisture include tillage without turning the top layer (reduced tillage) and leaving plant residues in the form of mulch or stubbles. On slopes soil tillage is adapted to retain draining overland flow.

According to the researchers, the main reasons for the low performance of agriculture in the region is the sub-optimal application of good land management practices like crop rotations and practices related to tillage, weeding, and the insufficient use of fertilizers (about 50 kg NPK/ha, whereas 150-200 kg/ha should be used in the region for the crop production systems studied), and pesticides.

From the land users' point of view the lack of credits and resources (fertilizers and equipment) cause problems with agricultural land management.

3.1.4 Greece

From the research team's point of view soil water repellency is an important soil related problem for irrigated agriculture, at least in coarse textured soils. Soil water repellency results in significant water losses (due to evaporation and runoff) and un-even distribution of irrigation water with corresponding poor plant growth (dry spots) (Ritsema and Dekker, 2003). Soil salinization was also mentioned by researchers as a major soil related problem in the East Nestos Delta region. The use of saline groundwater for irrigation purposes, the lack of freshwater sources and the limited awareness of the farmers, are factors responsible for land degradation and desertification in the region.

Figure 3-6 Dry spots and preferential flow pathways in an olive orchard in East Nestos Delta Region, Greece.

From the land users' point of view soil water repellency is a serious problem for the olive orchard investigated in the Waterreuse experiments. The farmer reported that the soil does not absorb water easily. After a strong irrigation event (flooding) the soil 5-10 cm below the surface was dry. It generally required large amounts of water for complete wetting. Tap water, is being used by the farmer for the olive orchard.Groundwater salinity is reported by land users as a significant problem in the wider region. The scarcity of fresh water resources is also reported as a major issue, since farmers have to pump (operational costs due to diesel pumps employed) water from adjacent streams and transport it several kilometres inland for irrigation. The revenues from crop yields are considered low by land users due to the low crop prices.

3.2 Objectives of water saving strategies

The objectives of the Water Reuse project were:

Overall objective: To develop new, and advance existing, sustainable water saving strategies in the NIS and Mediterranean States by focusing on largely unexploited opportunities for (a) water saving and (b) use of organic-rich waste water as a non-conventional water resource on irrigated land.

Specific objective 1: Develop strategies for the exploitation and advanced management of soil wetting characteristics to counter water losses which occur through surface runoff, evaporation and uneven wetting and preferential flow in the subsoil, and

Specific objective 2: Develop strategies for the use of organic-rich municipal, agricultural and industrial wastewater as an additional water resource for irrigation and nutrient source, and means for improving soil hydraulic properties and increasing medium-term carbon storage in soils.

Based on WPs 3 and 4, water saving strategies were selected and ranked by effectiveness with regard to the project objectives for all study sites using the results from the SWAP model (see deliverables 20[1] and 21[2]). The measures resulting from the most promising strategies were selected for investigation in field experiments. The ranking of the water saving strategies is summarized in Figure 3-7 below. This figure shows that irrigation with wastewater ranked highest as a strategy useful to test for the objectives of the Water Reuse project, followed by irrigation scheduling. It also shows that all sites have tested at least 2 relevant strategies. The evaluation and ranking of water saving strategies with regard to physical performance is described in Deliverable 25 (Moore et al., 2010).

Water saving strategy	Spain	Russia	Ukraine	Greece
Irrigation scheduling	🔴	🟡	🟡	🟢
Irrigation with waste water	🔴	🔴	🔴	🟡
Mulching	🟡		🟡	
Use of surfactant	🟢			🔴
Claying	🟡			🔴

Figure 3-7 Ranking of water saving strategies tested in study areas based on the SWAP model analysis for each site. Colors from green to red denote increasing rank order.

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[1] Evaluation of results from WP 3 and WP 4 with respect to water saving potential and applicability of proposed water saving techniques for each site

[2] Final selection of water saving approaches to be evaluated in field trials at each site based also on results from initial laboratory trials.

4 Biophysical conditions in the test applications of water saving strategies

The applicability of water saving strategies in an area is determined by biophysical and socio-economic conditions of the region. The biophysical conditions are the subject of this report. They can be subdivided in four groups according to Figure 4-1.

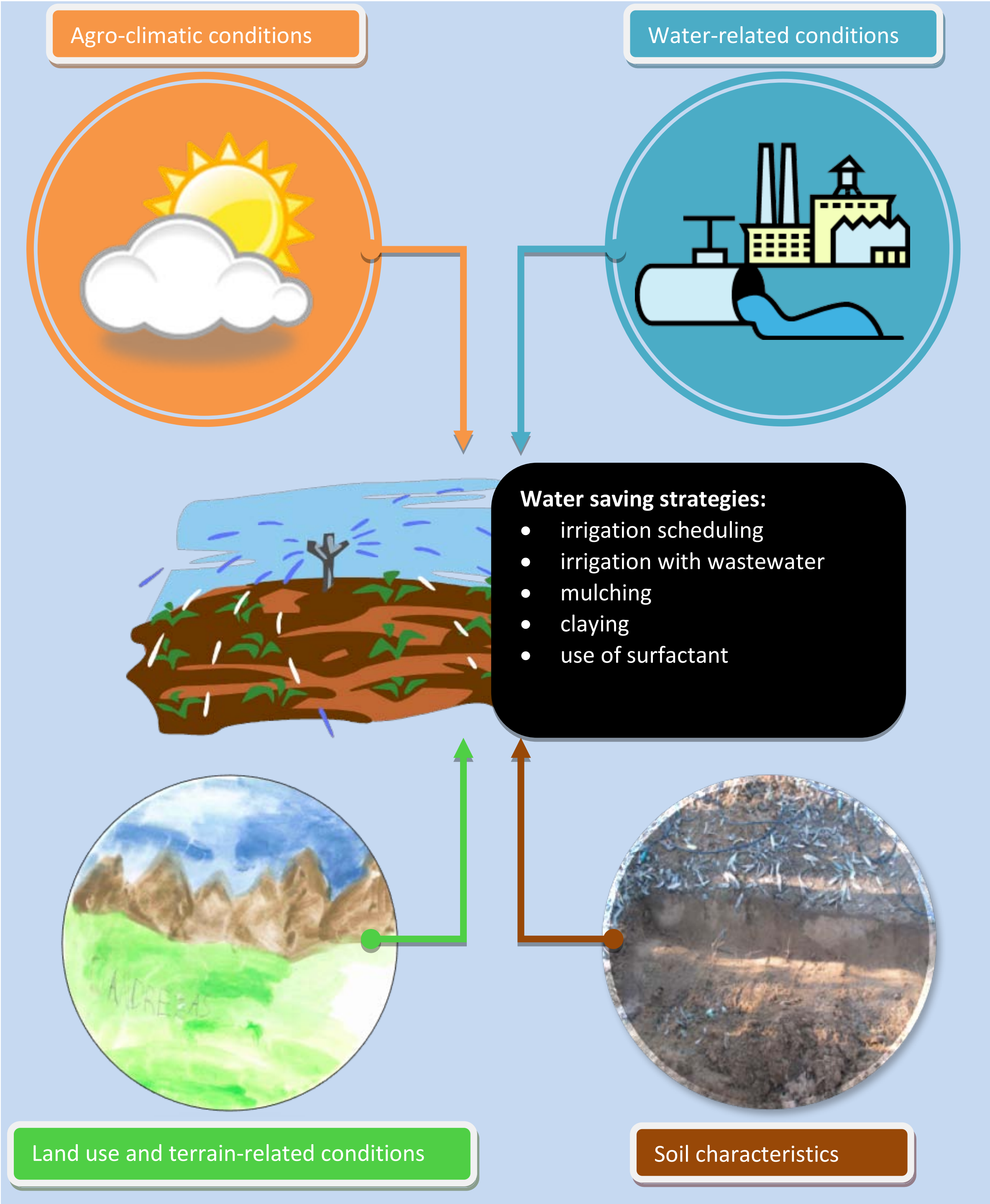


Figure 4-1 Main groups of biophysical conditions determining the applicability of water saving strategies.

4.1 Land use and terrain conditions

Figure 4-2 gives an overview of the land use and terrain conditions in the test applications of the water saving strategies. The land use typology as used in the WOCAT questionnaire on technologies was used (WOCAT, 2008) to indicate the land use types where the main types of water saving strategies were applied. The land use types concerned included tree cropping (all strategies), annual cropping (irrigation scheduling, irrigation with wastewater and mulching), and perennial cropping (irrigation scheduling and irrigation with wastewater). The tree cropping referred to vinegrapes (Figure 4-5) and olive trees in Spain and Greece. The annual crops included alfalfa, corn, oats and wheat in the Russian Federation and Ukraine (Figure 4-3). Finally, the use of surfactant and claying were trialled in a wasteland irrigated with wastewater during almost 20 years in Spain (Table 4-1).

	Land use type				Altitudinal zonation			Slopes	Landforms[3]	
Main water saving strategy	Ct	Ca	Cp	Oo	0-100	100-500	500-750	0-2%	Plateau/ plains[1]	Vally floors[2]
Irrigation scheduling										
Irrigation with waste water										
Mulching										
Use of surfactant										
Claying										

[1] Plateau / plains: extended level land (slopes less than 8 %).
[2] Valley floors: elongated strips of level land (less than 8 % slope), flanked by sloping or steep land on both sides.
[3]WOCAT, 2008

Figure 4-2 Overview of land use and terrain conditions in the test applications of water saving strategies. Land use types are explained in Figure 4-4

Figure 4-3 Wheat cultivation in Saratov Region, Russian Federation. Photo: A. Zeiliguer.

Table 4-1 Land use types where the main water saving strategies in each study area were applied. Land use types are explained in Figure 4-4.

Main water saving strategy	Alicante, Spain	Saratov region, Russia	Kharkiv region, Ukraine	Maggana region, Greece
Irrigation scheduling	Ct	Cp/Ca	Ca	
Irrigation with waste water	Ct	Cp/Ca	Ca	Ct
Mulching	Ct		Ca	
Use of surfactant	Oo*			Ct
Claying	Oo*			Ct

** The historical plot. Abandoned land that during approximately 20 years (1981-2000) was irrigated with waste waters with very low degree of depuration and during that period there was a Populus alba tree stand used as a "green filter". In 2000 the trees were cut and the land was abandoned.*

Land use type	*Subcategory codes*
Cropland: Land used for cultivation of crops (field crops, orchards).	• ***Ca: Annual cropping:*** *land under temporary / annual crops usually harvested within one, maximally within two years (eg maize, paddy rice, wheat, vegetables, fodder crops)* • ***Cp: Perennial (non-woody) cropping:*** *land under permanent (not woody) crops that may be harvested after 2 or more years, or only part of the plants are harvested (eg sugar cane, banana, sisal, pineapple)* • ***Ct: Tree and shrub cropping:*** *permanent woody plants with crops harvested more than once after planting and usually lasting for more than 5 years (eg orchards / fruit trees, coffee, tea, grapevines, oil palm, cacao, coconut, fodder trees)*
Other:	• ***Oi: Mines and extractive industries*** • ***Os: Settlements, infrastructure networks:*** *roads, railways, pipe lines, power lines* • ***Ow: Waterways, drainage lines, ponds, dams*** • ***Oo: Other:*** *wastelands, deserts, glaciers, swamps, recreation areas, etc*

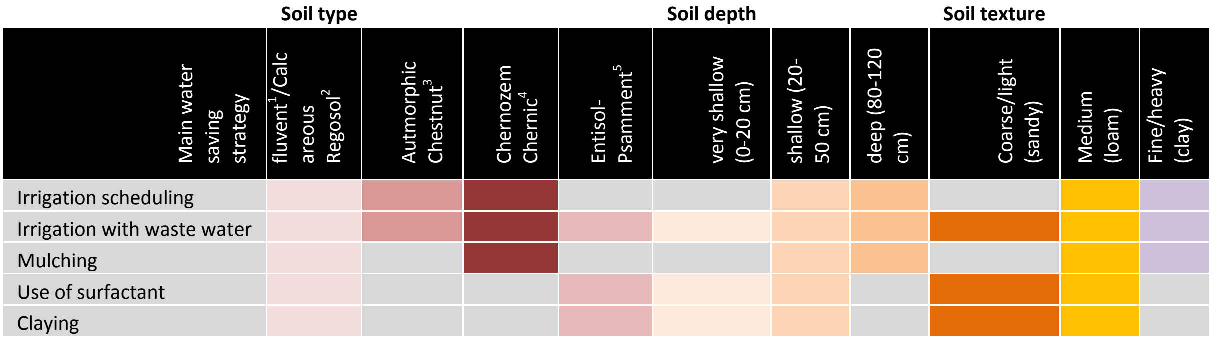
Figure 4-4 Land use typology (selected) from the WOCAT questionnaire on technologies for sustainable land management (WOCAT, 2008).

Figure 4-5 Vitis labrusca, the vinegrape used in the field experiments in Alicante Region, Spain.

The water saving strategies were tested in flat areas in the lower range of altitudinal zones (between 0 and 750 m ASL), which are mostly located in plateaus, plains and valley floors (Figure 4-2). The situation in lower altitudes is related to the ease to supply irrigation water from sources usually available in lower parts of the landscape from wastewater collection points or surface or groundwater water bodies, through channels, pipelines or in tanks. The application on terrain with smaller slopes is understandable as most strategies aim to optimize infiltration of irrigation water and rainfall, which will more easily be lost from the surface as runoff at steeper slopes. Therefore, the applicability of the strategies using irrigation water decreases with application at higher locations in the landscape and at steeper slopes. For the Ukrainian site, irrigation is specifically undesirable on slopes above 5° and on soils susceptible to water erosion (ISSAR, 2010). It is often found that the uniform application of irrigation water on areas with microrelief causes some areas to receive too much water and others too little (e.g. Bader et al., 2010; Playan et al., 1996; Zeiliguer et al., in press). For this reason irrigation is advised to be performed on preliminarily levelled areas in the Ukrainian site (ISSAR, 2010).

4.2 Soil characteristics

The soil characteristics in the areas for test application of the water saving strategies are shown in Figure 4-6 and Figure 4-9.



[1] SSS (2006): Soil Survey Staff, 2006. Keys to Soil Taxonomy. 10th ed. NRCS, Washington, DC
[2] WRB (2006): FAO, 2006. World Reference Base for Soil Resources. World Soil Resources Report 103, FAO, Rome.
[3] Russian soil classification system (1997)
[4] WRB (1998)
[5] USDA Soil taxonomy (1975)

Figure 4-6 Overview soil characteristics in the test applications of water saving strategies. Coloured cells denote the occurrence of a condition in one or more study areas.

For the soil type, the (sub-)orders in the soil classification systems used by the research teams in the study countries was mentioned, because a detailed assessment of the soil type would be required to perform a correct transformation of soil taxonomical classes. The soil types on which water saving strategies were trialled in the Water Reuse project have been selected because they require irrigation for crop production for various reasons, which include the low moisture retention capacity or the periodic lack of soil moisture in dry seasons.

All strategies were trialled in Calcareous Regosols in the study site in Alicante, Spain. Regosols are very weakly developed mineral soils in unconsolidated materials that are not very shallow or very rich in gravels, sandy or with fluvic materials. Regosols are extensive in eroding lands, particularly in arid and semi-arid areas and in mountainous terrain (Figure 4-7).Regosols with rainfall of 500–1000 mm/year need irrigation for satisfactory crop production (Lal, 2006). In the Alicante region, annual rainfall is below 500 mm (Table 4-3), and therefore water saving strategies should include forms of irrigation. The low moisture holding capacity of Regosols calls for frequent applications of irrigation water (Lal, 2006).

Figure 4-7 Areas in Europe where Regosols are the dominant soil type. Source: Soil Atlas of Europe, EC (2006).

Irrigation scheduling and irrigation with wastewater were also trialled on autmorphic chestnut soils in Saratov Region, Russia. These soils have formed on terraces of the Volga river, which are very suitable for agriculture when irrigation is applied (Kireycheva et al.). Chestnut soils in the Russian soil classification system correspond to Kastanozems in the WRB (2006) system due to the chestnut-brown colour of the surface soil. These soils are dark brown and rich in organic matter. They are part of the Eurasian short-grass steppe belt (southern Ukraine, the south of the Russian Federation, Kazakhstan and Mongolia), south of the Eurasian tall-grass steppe belt with Chernozems. Kastanozems are potentially rich soils, but the periodic lack of soil moisture is the main obstacle to high yields. Irrigation is nearly always necessary for high yields; care must be taken to avoid secondary salinization of the surface soil, as was also described in the major land use problems in the area (see chapters 3.1.2 and 3.1.3 and Figure 3-2). Phosphate fertilizers might be necessary for good yields (IUSS Working Group WRB. 2006). Small grains and irrigated food and vegetable crops are the principal crops grown; in the study area of the Saratov region alfalfa, and in the Ukrainian study site corn and winter wheat. Wind and water erosion is a problem on Kastanozems, especially on fallow lands (IUSS Working Group WRB. 2006). However, erosion was not reported as a land use related problem in the study areas in Russia and Ukraine.

Irrigation scheduling, irrigation with wastewater and mulching were trialled on Chernozems(WRB 1998) in the study area in Ukraine. Chernozems have a thick black surface layer that is rich in organic matter. According to the IUSS Working Group WRB (2006), Russian soil scientists rank the deep, central Chernozems among the best soils in the world. However, the favourable soil structure should be preserved through timely cultivation and careful irrigation at low watering rates in order to prevent ablation and erosion. Application of P fertilizers is required for high yields. Wheat, barley and maize are the principal crops grown, alongside other food crops and vegetables. In the study area in Ukraine, the crops grown include corn, spring wheat and winter wheat.

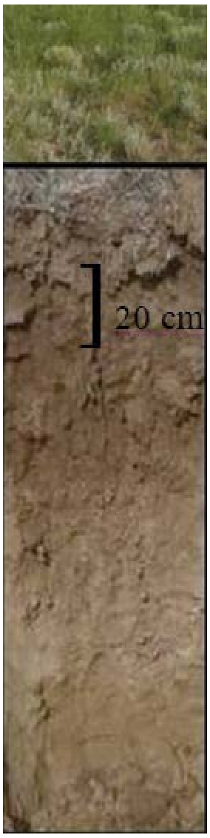


Figure 4-8 Chestnut soil in Saratov Region, Russian Federation. Photo: Anatoly Zeiliguer.

Irrigation with wastewater, the use of surfactant and claying were trialled in the study area in Greece on Entisols, suborder Psamment (USDA Soil Taxonomy, 1975). Entisols are defined as soils that do not show any profile development other than an A horizon. Most Entisols are basically unaltered from their parent material (http://en.wikipedia.org/wiki/Entisol). In the study area in Greece, this consists of unconsolidated sediment. Psamments are Entisols with sandy parent materials, covering about 3% of the Earth's surface. Therefore they are commonly low in plant nutrients, have low water-holding capacity and rapid permeability. These characteristics make irrigation indispensable for crop production. Irrigation and proper management may also help to prevent wind erosion (Lal, 2006).

Soils in which the strategies were trialled were shallow to very shallow (0-50 cm) for the areas in Spain and Greece (Figure 4-6), and deep for the study areas in the Russian Federation and Ukraine (80-120 cm). In the Greek site, below 20 cm coarse sand is found extending till below the water table. Irrigation with wastewater is better applicable in deeper soils in order to prevent runoff to other areas and channels.

Soil texture is medium for the Calcareous Regosol in the Spanish site and the Automotphic Chestnut soil in the Russian site, and fine to heavy in the Chernozems in Ukraine (Figure 4-6 and Table 4-2). The Entisols of the site in Greece have a coarse (sandy) texture. Soils with loamy and clayey textures, the study areas in Russia and Ukraine, have lower infiltration capacities than coarser soils, but higher water holding capacity. Fine soil textures increases the applicability of irrigation with wastewater depending on the water quality. Several common problems related to soil, water and cropping may occur under wastewater irrigation: decreased crop growth and permeability due to salinity of wastewater, toxicity of plants to sodium, chloride, boron, imbalanced nutrient supply, release of microbiological contents in the soil (Pedrero et al., 2010) and the influx of heavy metals in the soil and from there in the food chain with harmful effects on animals and humans. These problems are more prominent in fine-textured soils due to the greater binding of nutrients and heavy metals in soils with high values of cation exchange capacity, organic matter content and oxides of iron and alumunium (e.g. Sidle et al., 1977). Coarse textured soils, like in the study area of the Water Reuse project in Greece, appear to be more sensitive to the development of water repellency. Therefore, soil texture is a critical criterion for selecting water saving strategies.

Table 4-2 Soil texture in the study areas.

Soil texture	Study area
Coarse/light (sandy)	Maggana, Greece
Medium (loam)	Alicante, Spain; Saratov, Russia
Fine/heavy (clay)	Kharkiv, Ukraine

The water saving strategies were tested on soils with low to medium fertility (Figure 4-9), but organic matter contents were medium to high. For the Calcareous Regosols in Spain the relatively high soil organic matter content is attributed to the grass cover developed during the experiment and the manure added by the farmers in the past (UMH, 2010). Particularly the Entisol in the Greek site is characterized by a low fertility because nutrients are easily leached from the soil due to its high permeability. The low to medium fertility of the soils examined offers scope for irrigation with wastewater, since the effective use of nutrients contained in wastewater for irrigation has been widely reported to have the potential to increase crop production and decrease fertilizer application (e.g. Lazarova and Assano, 2005; Pedrero et al., 2010; Silva-Ochoa and Scott, 2004). Positive effects from wastewater use on crop yields were indeed observed in the study areas in Russia and Ukraine on respectively alfalfa and corn and wheat (see deliverable 25).

Irrigation with wastewater or raw greywater[3] may induce water repellency in sandy and loamy soils if the wastewater has high contents of dissolved organic matter (Wallach et al., 2005; Travis et al., 2010). This may have negative effects on soil permeability (e.g. Doerr, 2000). This effect was not observed in the field trials in the Water Reuse project. The results for Greece even suggest that the use of wastewater may even reduce water repellency in already water repellent soils (see deliverable 25).

In general, soil fertility and topsoil organic matter content increase the applicability of irrigation with wastewater. With regard to soil fertility, this is because any effort to increase the economic benefit of irrigation can best be performed on the most productive soils. With regard to topsoil organic matter content, the applicability of wastewater irrigation is larger because organic matter increases the infiltration capacity and water holding capacity of the soil.

[3] Greywater is the non-toilet portion of the domestic wastewater stream – i.e., bath, laundry, and kitchen wastewater (Travis et al., 2010).

	Soil fertility		SOM		Soil drainage/infiltration		Soil water storage capacity		
Main water saving strategy	medium	low	High (>3%)	Medium (1-3%)	Good	Medium	High	Medium	Low
Irrigation scheduling									
Irrigation with waste water									
Mulching									
Use of surfactant									
Claying									

Figure 4-9 Overview soil characteristics in the test applications of water saving strategies (continued).

Soil drainage and infiltration capacity are medium to good for all test applications of the water saving strategies (Figure 4-9). In the Greek study site, the internal drainage of the soil is excellent, but periodic rises of the groundwater table up till 40 cm below the soil surface may impede infiltration and drainage. Soils with good drainage capacity are better suited for irrigation with wastewater, but the applicability is conditioned by the quality of water, due to the risk of groundwater contamination in case soils are well drained.

On nonsodic soils, irrigation with wastewater may decrease the hydraulic conductivity, but increase that of sodic soils (Li et al., 2010). The positive effect on hydraulic conductivity in sodic soils is because wastewater usually has higher Na^+ and soluble salt concentrations. These inhibit clay swelling, dispersion and mobilization, and therefore increase soil aggregate stability and the maintenance of high soil hydraulic conductivity (Levy, 2000; Mace and Amrhein, 2001; Li et al., 2010). However, in nonsodic soils, Na^+ concentrations in the wastewater through the exchange of cations may lead to sodification[4], and consequently to the degradation of soil structure and hydraulic conductivity (Yoon et al., 2001; Gloaguen et al., 2007; EC, 2009; ISSAR, 2010). Sodic soils are those which have an exchangeable sodium percentage (ESP) of more than 15 (FAO, 1988).

The field experiments in the Spanish study site showed that the use of wastewater from secondary treatment for irrigation was characterized by high salt concentrations (high values of the electric conductivity) compared to fresh water and water from tertiary treatment.The soils in the Spanish study site can be considered nonsodic, having an ESP of 0.06% and 0.04 % measured at the start of the irrigation experiments on the plots with wastewater from secondary treatment and freshwater respectively. Based on the characteristics of the wastewater and soils, irrigation with wastewater on these soils might negatively affect soil drainage and infiltration through a decay of the soil structure. However, this effect was observed also in the treatments with fresh water and wastewater from tertiary treatment, and could not be demonstrated to be related to the high salt concentrations of the wastewater from the secondary treatment.

The soil water storage capacity is medium to high for all test applications, except for those in the Greek study site. This is favourable for all strategies targeted in the first place at increasing the soil moisture content of the root zone (irrigation scheduling, irrigation with wastewater, use of surfactant and claying). This was confirmed by the results of the field trials in several sites by the observed increased delivery of water to soil depths accessible for plant growth and increased soil moisture contents in the root zone compared to control situations.

[4]Sodification: the accumulation of water-soluble Na+ salts in the soil (EC, 2009)

4.3 Agro-climatic conditions

Figure 4-10 gives an overview of the agro-climatic conditions in which the water saving strategies were tested. The strategies were tested in areas with annual rainfall between 250 and 750 mm, except for the use of surfactant and claying, which were tested only in areas with annual rainfall between 250 and 500 mm. Details on the rainfall distribution in the test areas are given in Table 4-3. The dry period for the applications of most strategies is from June till September, and has a length of 2.5 till 4 months. The test applications were located in the sub-humid and semi-arid agro-climatic zones, which are characterized by a length of the growing period[5] of respectively 180-269 days and 75-179 days (WOCAT, 2008).

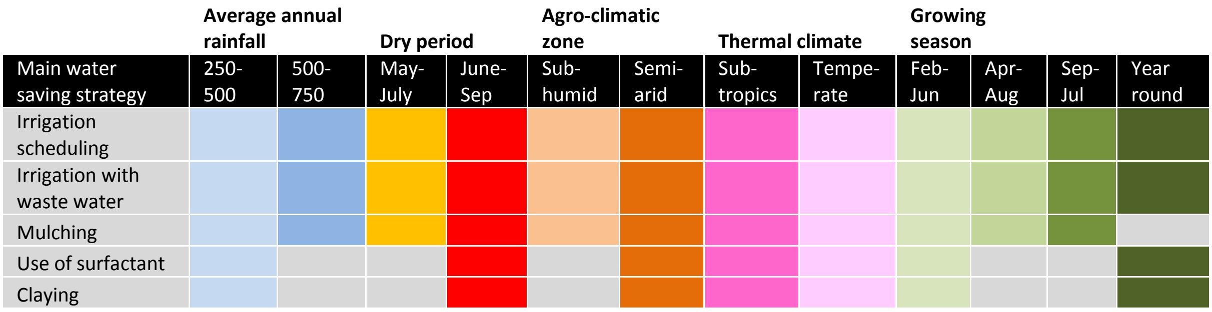


Figure 4-10 Overview agro-climatic conditions in the test applications of water saving strategies

The length of the dry periods, the growing periods and their timing in the year are important for the adaptation of water saving strategies to local applications, especially for the strategies based on irrigation (irrigation scheduling and irrigation with wastewater). For example in the Saratov region, the infiltration capacity of soils is worst in dry conditions during the dry period, when winds are strong and the evapotranspiration is high. Therefore more frequent irrigation applications are necessary in smaller doses to obtain sufficient soil moisture contents in the root zone, and irrigation scheduling will give the best results in areas where dry periods coincide with growing periods.

Areas in semi-arid agro-climatic zones are characterized by large periods with minimum rainfall and high evapotranspiration. These conditions result in soil drying. Soil water repellency may occur when the soil moisture content drops below a critical threshold. Therefore these areas are most at risk for the development of soil water repellency. Consequently, for the strategies aiming at the improvement of soil wettability through the use of surfactant or claying, the best performance is obtained when soil moisture content is below the threshold for the development of soil water repellency, like in the summer period in the Greek study site, with average rainfall < 120 mm.

[5] The length of growing period (LGP) is defined as the period when precipitation > 0.5 PET (potential evapotranspiration) and the temperature > 6.5° C (definition used in the WOCAT questionnaire on technologies, WOCAT, 2008).

Table 4-3 Average annual rainfall, seasonality and length of dry periods in study areas.

Average annual rainfall (mm)	Study area	Average annual rainfall (mm) and seasonality (e.g. monsoon, winter/summer rains)	Length of dry periods
< 250			
250-500	Maggana, Greece	550 mm Wet winter period from November to April (5 months)	Dry summer period from June to September (4 months)
	Alicante, Spain	486.0 mm annual 134.5 mm Spring (March-May) 79.1 mm Summer (June-Aug) 170.9 mm Autumn (Sept-Nov) 101.4 mm Winter (Dic-Feb)	The length of dry period is mainly in summer: June-September, some years more (October)
	Saratov, Russia	400 mm Snow winter time from the beginning of December to the end of March (4 months)	Dry summer time period is from beginning of May to and of July (2 – 2,5 months)
500-750	Kharkiv, Ukraine	511.0 mm annual 161.7 mm growing season (Apr.-Sept. 2009)	The period without a rain in May-July can reach 60 days
750-1000			
1000-1500			
1500-2000			
2000-3000			
3000-4000			
>4000			

All water saving strategies were tested in areas with temperate of subtropical thermal climate (Figure 4-10). The thermal climate expresses the intra-annual variation of mean monthly temperatures in an area. Temperature is an important variable to consider in the design of water saving strategies, because high temperatures cause increased losses of green water from soils through evapotranspiration. A temperate thermal climate is defined as having at least 1 month with monthly mean temperatures[6] below 5° C and 4 or more months above 10° C. The study areas in the Russian Federation, Ukraine and Greece have a temperate climate. In combination with the dry period of the year and string wind, the temperate thermal climate causes dryness of the root zone and water stress for crops in these areas. Apart from the direct effect of deficient soil moisture to crops, the dryness of the soil may cause a low soil hydraulic conductivity (Russian Federation) and soil water repellency (Greece), which in turn may increase crop water stress. A subtropical thermal climate has one or more than one month below 18 ° C but above 5 ° C (definitions from FAO 2000, used in the WOCAT questionnaire for technologies on SLM: WOCAT, 2008).

The water saving strategies were tested in areas and on crops with growing seasons covering different parts of the year (Figure 4-10 and Table 4-4). A growing season is a period of time where there is sufficient rainfall and moisture in the soil as well as high enough temperatures to grow a crop (WOCAT, 2008). The applicability of the water saving strategies depends on the timing of the crop water requirements during the growing season compared to the availability of soil moisture

[6] All temperatures indicated as monthly mean temperatures corrected to sea level)(Source (FAO 2000, in:WOCAT, 2008).

and rainfall. Irrigation scheduling and irrigation with waste water are best applied in situations where crop growth is inhibited during the growing season due to deficient rainfall. In designing irrigation scheduling, it is important to realize that a soil water deficit does not inhibit crop growth unless it also inhibits evapotranspiration (ET) (FAO irrigation manual, cited in Greenwood et al., 2009). This implies that high yields of many crops can be obtained even when the soil moisture content to the depth of rooting is maintained far below that at field capacity (Greenwood et al., 2009). In case of perennial crops, the use of water saving strategies based on irrigation (irrigation scheduling and wastewater irrigation) care should be taken that the absence of tillage operations may lead to compaction of the topsoil with negative effects on the infiltration capacity of the soils. This is the case in the Saratov region in the Russian Federation.

Table 4-4 Crops and growing seasons in the regions for test application of the water saving strategies.

Study area	Crop or crop rotation	From which month to which month
Alicante province, Spain	grapevine	February-June
Saratov region, Russia	Alfalfa	All year
Kharkiv, Ukraine	maize (2006 & 2008) winter wheat (2007) spring wheat (2009)	April – August September - July April – August
Maggana region, Greece	Olive tree	All year

4.4 Water-related conditions

An overview of water-related conditions in the areas where the water saving strategies were tested is given in Figure 4-11. It shows that all strategies are applicable in situations where the groundwater is rather deep (between 5 and 50 m), which also explains the need to reduce water loss from the root zone. In Alicante region, Spain, the groundwater level varies between 10 and 20 m from the surface during the year. Also in Ukraine the groundwater table is deep, at 20 m below the surface on average. In the Saratov region the groundwater table is closer to the surface (7-10 m) in spring time, and rises after irrigation applications.

In Maggana region, Greece, the situation is different, with the groundwater table on average at less than 5 m from the surface, with variations from 0.5 m during winter and spring, to 2.2 m during summer and autumn. Despite the proximity of the groundwater table to the surface, the root zone may experience a soil moisture deficit due to the large permeability of the soil. Water saving strategies based on irrigation are less useful here; instead strategies aiming at improving the wettability of the soil are more appropriate.

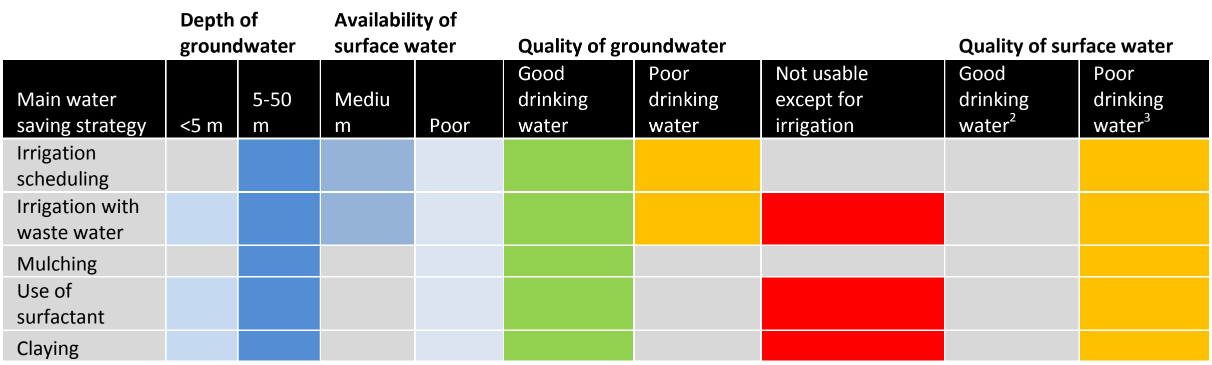


Figure 4-11 Overview water-related conditions in the test applications of water saving strategies

All strategies were tested in areas where, as expected, the availability of surface water is poor. The more limited the availability, the more applicable water saving strategies are. In Alicante region, Spain, in July and August usually less than 20 mm of rain is received. In the study region in Ukraine, surface water deficiency is common, especially with the increasing frequency of dry years. In Maggana region, Greece, there is no surface water available to fields like the experimental olive orchard. Groundwater is of poor quality, and therefore farmers use water from the tap for irrigation. This makes the use of treated wastewater an interesting alternative for irrigated agriculture (Figure 4-12). In addition, the nutrients and organic matter present in the effluents used can be recycled to the soils. In Saratov Russia, the availability of surface water is best, because water for irrigation is supplied by channels which form part of large irrigation systems. However, for irrigated fields at long distance from the irrigation channels, water availability is also limited. In these cases, the use of treated wastewater is an interesting alternative.

Figure 4-12 Disposal lagoon for olive mill wastewater management in Greece (Xanthi). Photo: Vasilis Diamantis.

The quality of groundwater is medium to good in the test applications of irrigation scheduling, irrigation with wastewater and mulching in Spain, Russia and Ukraine (Figure 4-11 and Figure 4-13). Here, the tested water saving strategies based on irrigation offer an alternative source of irrigation water from precious groundwater resources. The quality of the groundwater is worst in Maggana region, Greece, where the salinity prevents its use as a resource for irrigation. In all regions, the available surface water is of poor quality as drinking water, but usable for irrigation. In Maggana region, Greece, surface water is not available. In general, the scarcity (depleting groundwater bodies or limited availability of surface water) or poor quality of groundwater and surface water increase the applicability of water saving strategies, and especially irrigation with wastewater as an alternative source.

Water source	Alicante, Spain	Saratov, Russia	Kharkiv, Ukraine	Maggana, Greece
Ground water	✓	!	✓	✗
Surface water	!	!	!	n.a.

Quality grades:

✓ Good drinking water

! Poor drinking water

✗ Not usable for any purpose other than possibly irrigation

Figure 4-13 Quality of surface and groundwater in the regions for test application of the water saving strategies.

4.5 Importance of biophysical factors for applicability of water saving strategies

The importance of the biophysical factors discussed above for the applicability of water saving strategies was indicated by the research teams in the study regions (Table 4-5). Overall, most factors were considered important in three of the four investigated regions. Agro-climatic conditions and soil texture, soil fertility and topsoil organic matter content were considered important in all environmental settings of the study regions.

The agro-climatic conditions matter because they indicate the extent and timing in the year of crop water deficit as governed by the amounts and timing of rainfall and evapotranspiration. An exception to this observation is the length of the growing period, which was not considered important for the applicability of water saving strategies in the regions in Ukraine and Greece. For Ukraine, this is probably because the growing period encompasses the dry period of the year for all crops studied, and is not a discriminating factor for the type of water saving strategy to select. For the study region in Greece, the crop investigated was a perennial tree crop (olive), with a year-round growing period. Therefore the length of the growing period was not discriminating.

The importance of soil texture, soil fertility and topsoil organic matter content was motivated by the notion that any effort to apply water saving strategies with the purpose to increase the profitability of agriculture is best focused on the most favorable biophysical settings for crop growth apart from the limitations set by water scarcity.

Least important for the applicability of water saving strategies were considered factors expressing the relief of the terrain: the altitudinal zonation and landforms.

Table 4-5Importance of biophysical factors for applicability of water saving strategies.

	Alicante province, Spain	Saratov region, Russia	Kharkiv's oblast, Ukraine	Maggana region, Greece
average annual rainfall, seasonality, dry periods	✓	✓	✓	✓
agro-climatic zone	✓	✓	✓	✓
thermal climate	✓	✓	✓	✓
length of growing season	✓	✓	✗	✗
altitudinal zonation	✓	✗	✗	✗
landforms	✓	✗	✗	✗
slope	✓	✗	✓	✗
soil depth	✓	✓	✓	✗
soil texture	✓	✓	✓	✓
soil fertility	✓	✓	✓	✓
topsoil organic matter content	✓	✓	✓	✓
soil drainage/infiltration	✓	✓	✓	✗
soil water storage capacity	✓	✓	✓	✗
depth of groundwater table	✓	✓	✓	✗
availability of surface water	✓	✗	✓	✗
quality of surface and ground water	✓	✓	✗	✓

5 Identification of areas where the environmental conditions exist for successful use of the water saving strategies

5.1 Outcomes of tests on water saving strategies in terms of the objectives of the Water Reuse project

The outcomes of the field experiments on water saving strategies are indicative of the biophysical conditions under which the strategies are likely to be effective, and also of the possible adverse effects on those biophysical conditions, in particular soil and water-related conditions. The biophysical conditions include the conditions related to land use and terrain, climate, soils and water described in chapter 4. The detailed outcomes of all tests are described in deliverable 25. Below, the main outcomes are summarized for each of the study regions in Spain, the Russian Federation, Ukraine and Greece, and indications deriving from the main outcomes for all study areas are synthesized.

5.1.1 Alicante province, Spain

Irrigation scheduling

- Irrigation scheduling, in combination with mulching, increased the aggregate stability of the soil surface, thus decreasing negative effects of drying and wetting cycles on soil wettability.

Irrigation with wastewater

- Irrigation with wastewater did not lead to the development of water repellency, as is often reported in the literature (e.g. Wallach et al.,2005; Wiel-Shafran et al., 2006; Tarchitzky et al., 2007; Travis et al., 2010). The development of water repellency was not expected in the long term due to the fact that organic matter content was not observed to be increasing in the soil during the 3 year trial period.
- Irrigation with wastewater did not result in the accumulation of heavy metals in the soil, also a commonly reported environmental problem associated with the use of wastewater for irrigation (e.g. Qadir et al., 2007; Pedrero et al., 2010).
- Chemical and physical soil properties were not greatly influenced due to the use of wastewater for irrigation instead of fresh water.
- Adverse effects of waste water use were observed on crop growth, but it is not clear if this is due to the water used or the early development stage of the crop.

Mulching

- Mulching had positive effects on soil aggregate stability, but did not increase soil moisture content.

Claying

- The amendment of kaolinite clay resulted in reduced soil water repellency in an already water repellent soil.

Use of surfactant

- The use of surfactant reduced the water repellency of an already water repellent soil, but fresh water had the same effect.

These outcomes suggest that the combination of soil characteristics, agro-climatic conditions and water-related conditions in the test applications of the water saving strategies in Alicante province supported the objectives of the Water Reuse project to better employ soil wetting characteristics and reduce irrigation water losses, and to use wastewater as an alternative resource for irrigation. In particular the use of wastewater for irrigation was favourable in terms of impacts on the environment (human health and soils), though fertilising effects were not observed. The results offer scope for the application of the tested strategies in areas with biophysical conditions similar to the Alicante region. However, possible adverse effects from the use of wastewater from secondary treatment on crop growth require further research.

5.1.2 Saratov Region, Russia

The results from the field experiments on water saving strategies in the Saratov region referred to the infiltration capacity and irrigation management, and to the use of alternative water resources for irrigation management.

Infiltration capacity and irrigation management

- The use of secondary treated industrial wastewater did not result in the appearance of soil water repellency in a loamy soil with alfalfa perennial cropping.
- Irrigation scheduling by reduction of doses and frequency of application diminished the percolation of irrigation water to below the root zone.

Alternative water resources for irrigation

- The use of secondary treated industrial wastewater resulted in an increased yield of alfalfa biomass and corn compared toirrigation with freshwater.
- Irrigation with wastewater did not result in significant changes of soil water repellency and soil chemical properties like sodium content or heavy metal contents.

Figure 5-1 Field experimental work in the Saratov Region, Russian Federation. Photo: S. Zatinasky.

Overall, the results from the field experiments in the Saratov region indicate that irrigation scheduling and the use of wastewater for irrigation are positive for irrigation management, and invite to considering the use of wastewater for irrigation as a serious alternative to freshwater resources in biophysical contexts similar to those in the Saratov region. In particular, irrigation scheduling has three major positive effects with regard to irrigation management. In the first place the water availability to crops is augmented. A second positive effect is that the decreased seepage of irrigation water to the groundwater helps to control groundwater levels and through this the ecological situation in irrigation fields and adjacent territories. This is especially of value in case wastewater is used for irrigation. The third positive effect is that the maintenance of a deep groundwater position protects the topsoils from salinization/alkalinisation with concomitant negative effects on crop growth and soil hydraulic properties.

5.1.3 Kharkiv region, Ukraine

- The field experiments demonstrated that the use of wastewater for irrigation resulted in increased yields of wheat and corn and increased water use efficiency.
- Irrigation with wastewater did not result in adverse effects on soil parameters, including no increase in soil water repellency, provided that the composition of wastewater from pig farms is controlled. Positive effects on soil parameters included the increase of total available water in the soil.
- Irrigation scheduling and mulching (Figure 5-2) resulted in a faster, more complete and more uniform wetting of the rootzone and reduced losses in evaporation from ponding, losses due to preferential flow and losses to deep percolation.

Figure 5-2 Manual sprinkling (left) and mulching of plots after sowing in the field experimental site in Khariv Region, Ukrain. Photos: Tatyana Laktionova.

The results indicate that irrigation scheduling and irrigation with wastewater in combination with the biophysical conditions at the site and the selected crops offer scope for the wider application of these strategies in areas with biophysical conditions similar to those in the study area. Considering that the use of wastewater for irrigation in Ukraine is subject to strict control since the 1990s, the results from the Water Reuse experiments give cause for a return to the situation before 1990, when irrigation with wastewater was applied on extended surfaces in Ukraine.

5.1.4 Maggana region, Greece

The main results from the field experiments on water saving strategies in Maggana region, Greece, refer to the improvement of the wetting properties of soils and to the use of wastewater as an alternative resource in irrigation.

Management of wetting properties of soils

- The use of secondary treated municipal wastewater did not increase soil water repellency of a sandy soil with olive trees and grass cover. In contrast, a slight decrease of water repellency was observed under summer conditions compared to the soil irrigated with freshwater. The presence of residual surface active compounds and hydrophilic acids is thought to cause the slight increase in soil wettability.
- The use of olive mill wastewater in irrigation decreased soil water repellency some weeks after application.
- The use of commercial surfactant was beneficial for decreasing water repellency immediately after application.
- The use of clay in suspension was also beneficial for decreasing water repellency.

Alternative water resources for irrigation

- The use of secondary treated municipal wastewater resulted in high biomass production (grass cover) compared to the soil irrigated with freshwater alone.
- No significant changes in soil chemical properties (heavy metalcontamination, major ions and cations) were observed after irrigation with treated wastewater.

Figure 5-3Experimental design for testing treated wastewater application on soil water repellency. Photo: Vasilis Diamantis.

The results from the field experiments on water saving strategies in the Greek study area indicate that under the biophysical conditions of the site, the use of various types of wastewater, commercial surfactant and claying helps to improve the wetting properties of soils by reducing soil water repellency, and therefore help to reduce water losses from rainfall and irrigation. The results also show that the use of wastewater from municipal sources may increase the biomass of cover crops, and has no adverse effects on soil chemical properties.

5.2 Biophysical conditions under which the strategies are likely and not likely to be effective and identification of potential areas for application

5.2.1 *Alicante province, Spain*

In semi-arid conditions, like those in Alicante region, Spain, the scarcity of fresh water, rain and high temperatures keep the soils very dry and in many cases unproductive. In these circumstances, irrigation with wastewater is likely to be effective, because it offers the possibility to keep soil moisture contents at minimum levels required for crop growth at low costs. Semi-arid areas cover a large part of Spain (Figure 5-4). However, within these areas, care should be taken to prevent surface runoff and erosion from irrigation on sloping land. Therefore valley floors and foot slopes are likely to be the better locations to apply water saving strategies based on irrigation.

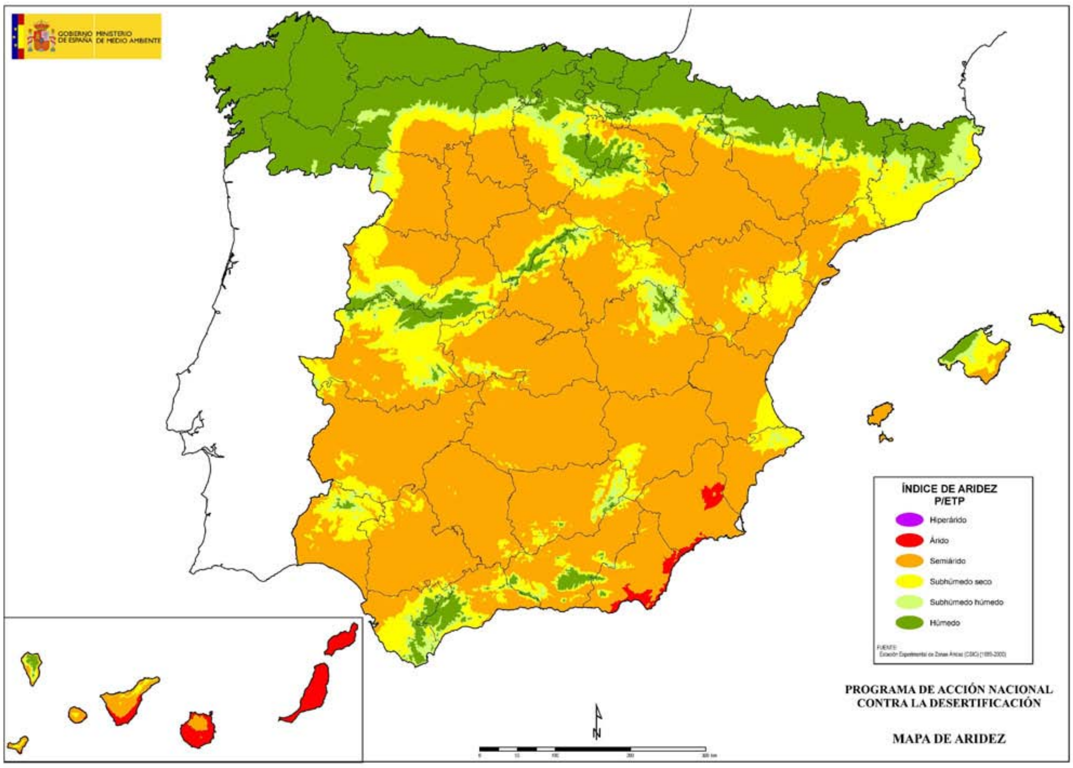


Figure 5-4 Agro-climatic zones in Spain, based on the aridity index. Source: Spanish Ministry of Environment (http://www.mma.es/images/general/biodiversidad/desertificacion/1_Aridez_red1.jpg). Semi-arid zones in orange shading.

Limitations to the application of the tested water saving strategies in the Spanish study area with regard to environmental conditions mainly refer to the quality of the wastewater used. The wastewater used in the field trials was representative of the water used in the Valencian Community Region in Eastern Spain. Based on the experimental results, this water proved to be a suitable alternative resource for irrigation with the aim to reduce water losses and to save freshwater resources. However, the main problem regarding the water quality was the high salt content testified by the high electrical conductivity of the wastewater from secondary treatment during a part of the experimental period of the study, which possibly affected crop growth and soil wetting characteristics, though this could not be reliably demonstrated in the field trials. Therefore it is recommended that for crops sensitive to soil salinity, like almond, beans and fruit crops (apricot, orange, peach, strawberries) (UC ANR, 2002), tertiary treatment is applied to wastewater, and that the electric conductivity and sodium content of the water are monitored to avoid problems with crop yield and crop quality and possibly reduced soil infiltration capacity due to salinization and sodification.

The problem of reduced soil infiltration capacity could be amplified because the calcareous, loamy soils used in the field trials are nonsodic. This causes them to be potentially sensitive to the deterioration of the soil structure due to the high content of sodium salts and other salts in the wastewater from secondary treatment (e.g. Al-Hamaideh and Bino, 2010). These soils are very common in the eastern and southeastern part of Spain, though the Mediterranean region is characterized by a wide variety of soils. It is recommended that the use of wastewater from municipal sources of different quality in combination with different soil types in the semi-arid regions of Spain is given more consideration in future research.

Figure 5-5 Wastewater treatment plant of Biar, Alicante. Source: UMH (2006).

Areas with similar soils and quality of wastewater in the Spanish Mediterranean region where the tested water saving strategies might be applicable include the regions of Andalucia, Castilla la Mancha, the Ballearic Islands, Catalonia, Murcia and the Valencian Community. In other regions with similar soils and wastewater quality outside Spain the strategies could also be used, like in Greece, Italy, Turkey, Morocco, Algeria and Israel .

5.2.2 Saratov region, Russian Federation

Based on the field experimental trials in the Saratov region, the environmental conditions in which irrigation with wastewater would be most effective include:

- Semi-arid environments with limited rainfall and a long dry period
- Scarce freshwater resources for irrigation purposes.
- Intermittently high levels of saline groundwater risking the occurrence of soil salinization and alkalinization

In applying wastewater irrigation, care should be taken not to increase the risk of deteriorating soil hydraulic properties, which would undo the beneficial effects of wastewater irrigation. The following conditions increase the risk of deteriorating soil hydraulic properties as a result of irrigation:

- Shallow levels of saline groundwater, particularly rich in sodium
- The use of wastewater with high concentrations of sodium
- Loamy or/and clayey soil texture sensitive to sodification (montmorolinite or smectite clay minerals)
- Low soil organic matter contents (partly due to leaching)

- Inappropriate irrigation scheduling. This is often related to the use of outdated irrigation technologies, like pivotal irrigation systems programmed to apply large doses at low frequencies (e.g. Pankova and Novikoba, 2000) (Figure 5-6).

Figure 5-6 Pivot sprinkler irrigation system (left) and supplying irrigation channel (right). Photograph: Wisse Beets.

Based on these conditions, it is recommended that in environmental settings similar to the Saratov region, wastewater irrigation is combined with irrigation scheduling to keep the root zone at soil moisture contents corresponding to (minimum) crop water requirements, while at the same time preventing percolation of wastewater from the root zone to the groundwater, and on the other hand capillary rise of saline groundwater to the root zone.

Suitable environmental conditions for the application of irrigation scheduling and wastewater irrigation include the regions in the Southern part of Russia between the Volga River and Don River, and the regions near the northern Caucasus and along the middle part of the Ural river in Kazakhstan (Figure 5-8). These areas include also parts of southern Ukraine, Romania, Moldavia and Bulgeria. These areas are all characterized by a scarcity of fresh water resources. The application of irrigation with wastewater is conditioned by the proximity of agglomerations producing wastewater and treatment plants (Figure 5-7).

Figure 5-7 Pond for sewage collection in Saratov Region, Russian Federation. Photo: S. Zatinatsky.

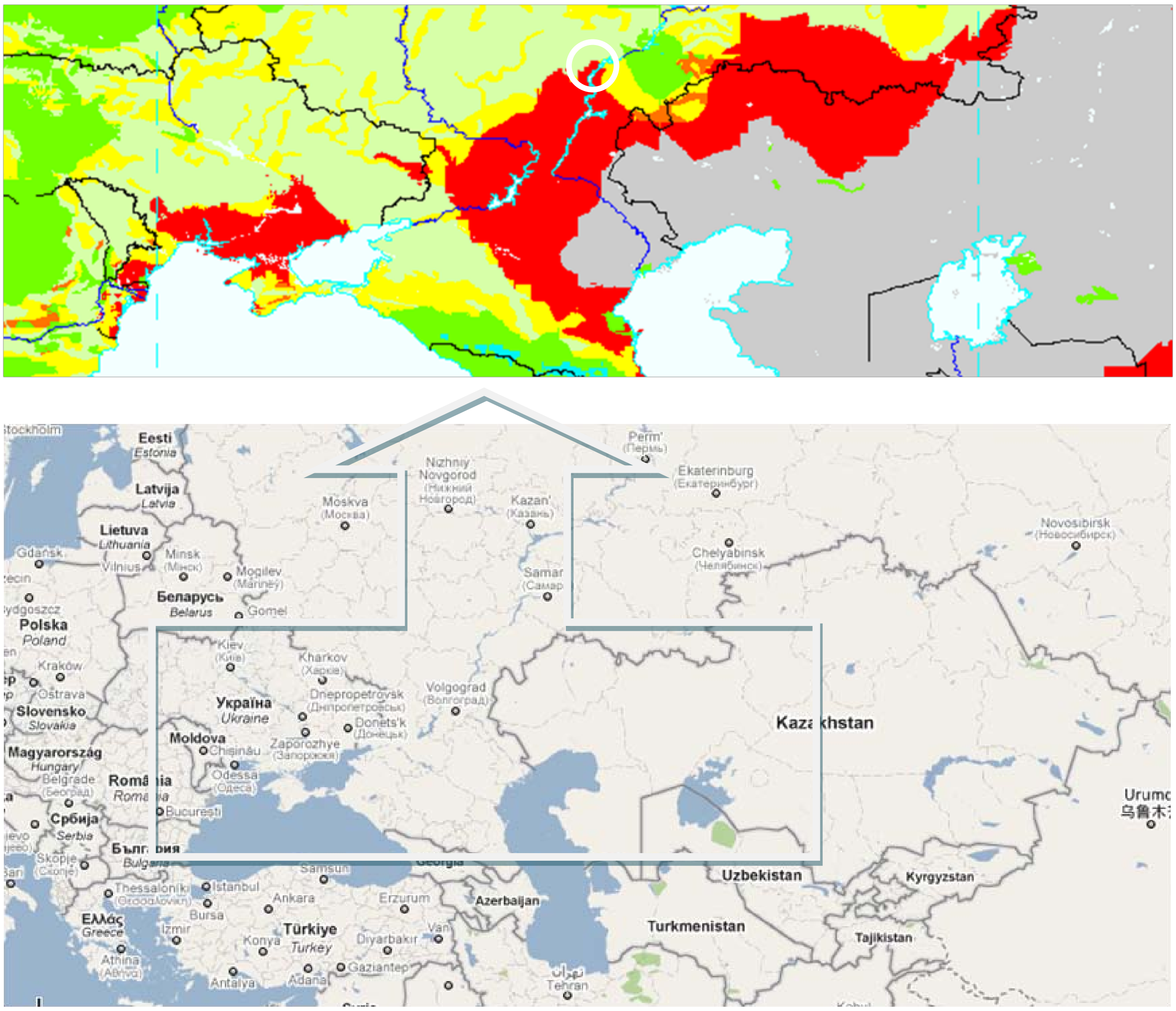


Figure 5-8 Potentially suitable areas for the application of irrigation scheduling and wastewater irrigation in the southern part of the Russian Federation and Kazakhstan (red).White circle indicates location of the study site. Source upper map: Anatoly Zeiliguer, MSUEE (2010). Source lower map: Google Maps, 2010.

Outside Eurasia, similar combinations of agroclimatological zone, land use, soils, limited availability of fresh water resources exist in Australia, New Zealand, Brazil, Chile, the US and Canada.

5.2.3 Kharkiv region, Ukraine

According to the researchers and experts involved in the Water Reuse field experiments, irrigation scheduling in combination with mulching will be effective in areas with soils with a non-leaching water regime, and sensitive to structural decay due to drop impact from sprinkler irrigation. This generally applies to all (irrigated) Chernozem soils in the south-eastern part of the Forest steppe and Steppe zones of Ukraine (Figure 5-9). Due to the non-leaching water regime, agricultural production on these soils depends to a large extent on irrigation.

These soils are also sensitive to cracking when drying. Therefore irrigation water loss due to preferential flow may occur in these soils. The effect of mulch is to delay the infiltration rate of irrigation water and thus to increase the water available to the crop.

Figure 5-9Water regime of Ukrainian soils (Source: Atlas of Ukrainian soil properties maps, CD.-T.Laktionova, V.Medvedev et al., 2006, Ukr.)

Code	*Name of water regime*	*Soil moistening source*
1	Leaching	Atmospheric precipitates
2	Leaching	Ground- Atmospheric including allochthonic waters
3	Leaching	Ground- Atmospheric including flood waters
4	Periodic leaching	Atmospheric and Atmospheric with additional surface moistening
5	Nonleaching	Atmospheric precipitates
6	Desuctive-exudative and Exudative	Ground- Atmospheric and Atmospheric-Ground at close allochthonic waters
0	Ponds	

Conditions under which the water saving strategies are likely to be not effective include the application on sloping terrain and application of the strategies in combination with irrigation water supply by channels, due to the risk of soil erosion and the removal of mulch by overland flow. The use of mulch, if uncontrolled, may endanger the application of irrigation scheduling due to the incidence of pests and diseases. This situation contrasts with experiences in Europe, where mulch combined with no-tillage has been promoted and adopted as an agri-environment measure in several EU member states, and the incidence of pests and diseases under mulching is much more controlled, though implementation problems with weed and disease (fusarium) infestation have also been reported (DE, 1996; LU, 2002; DED, 2007) (SoCo project team, 2009).

Land users have given the following recommendations for the environmental conditions in which to apply the tested water saving strategies:

- Irrigation with treated wastewater can be high in (semi-)arid zones having sources of good-quality waste water and significant areas under fodder cultures.

- Irrigation scheduling may be effective in regions with a shortage of water resources for irrigation, or for irrigation of cultures for which compliance with national irrigation standards is required (usually vegetables).
- Land users are well aware of the water saving potential of applying irrigation during night time.

Land users notice a risk for the application of irrigation scheduling and irrigation with wastewater in the southern part of Ukraine where dark, alkaline chestnut soils prevail (Figure 5-9). This is due to the susceptibility of these soils to cracking and consequent loss of irrigation water to percolation from the root zone to the groundwater. Land users are aware of the adverse ecological effects of the loss of irrigation water to percolation, mentioning the rise of the groundwater level, water logging and salinization. They recommend the preparation and protection of the soil surface before irrigation in order to prevent percolation.

On identifying suitable areas for the application of irrigation with wastewater, it should be realized that the use of wastewater for irrigation of agricultural crops is prohibited since 1990. When fresh water resources become more scarce in the near future, this prohibition is likely to be relieved. This would open up possibilities to apply wastewater irrigation around the large industrial centers in the Steppe and Forest Steppe zones, where wastewater irrigation had been successfully practiced until 1990. These include the suburban territories near Odessa, Mariupol, Simferopol, Kiev and Kharkiv.

5.2.4 Maggana region, Greece

The environmental conditions motivating the trialling of water saving strategies in the Greek site as part of the Water Reuse project include the occurrence of coarse textured, water repellent soils in a semi-arid environment with limited rainfall and a long dry period, and limited availability of fresh water resources. In addition, the vegetation cover is an important factor affecting the appearance of soil water repellency. According to Doerr et al. (2000), plants most commonly associated with the cocurrence of water repellency in semi-arid environments include evergreen tree types like eucalypt and pine, Mediterranean shrubland (Giovannini et al., 1987), and, in other environments, also grass on pasture (e.g. Crockford et al., 1991).

The broader region of the study site (East Nestos Delta region) has environmental conditions similar to those in the site used for the field experiments (Figure 5-10b). During a previous research project (www.water-repellency.alterra.nl), water repellent soils were detected in the broader region of Eastern Macedonia and Thrace. The most important factors were determined to be soil texture (coarse soil) and the vegetation and crop types: winter wheat, olive trees and natural grass cover increased soil water repellency.

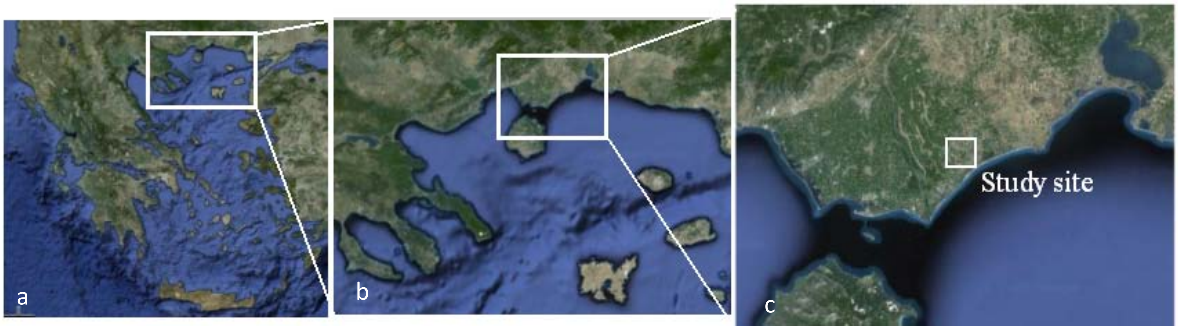


Figure 5-10 Location of the study site in Maggana Region in the Northern part of Greece. Source: Vasilis Diamantis, DUTH (2010).

The southern part of Greece and especially the Islands encounter serious water scarcity problems (Figure 5-11). They are characterized by long dry periods, significantly longer compared to the northern part of Greece. Under these conditions the reuse of treated wastewater and increasing soil wettability are important factors for sustainable agriculture, water resources management and environmental protection. Municipal wastewater treatment plants are already in operation in different islands, offering possible supplies of effluents to be reused after advanced treatment for irrigation purposes.

Olive oil production is a significant branch of trade for Greece. The wastewater produced during olive oil production is usually disposed into evaporation ponds. This material could be reused to increase the soil wettability for irrigated land.

The use of commercial surfactants is of significant importance for regions with limited access to freshwater supplies, such as the Greek islands

The use of clay is of significant concern for coarse textured soils, and can contribute to an increase of soil wettability.

Figure 5-11Location of the Aegean Islands in the Southern part of Greece. Source: Vasilis Diamantis, DUTH (2010).

6 Summary and conclusions

Several problems in sustainable land and water management motivate the (re)introduction of water saving strategies in the regions in the NIS and Mediterranean investigated in the Water Reuse project. These problems mainly relate to soil conditions, water conditions and land management. According to the research teams and consulted land users, salinization is the most frequently mentioned problem related to soil, the scarcity of fresh water is the most frequently mentioned water related problem, and low crop productivity is the most frequently mentioned land management problem.

Soil salinization
Problems due to soil salinization are most prominent in the study regions in Russia, where salinization is caused by irrigation in past decades, which caused groundwater levels to rise. Apart from salinization, the rising groundwater tables caused water logging and decreased soil organic matter due to leaching, leading to soil compaction, damage of soil structure, and worsening of soil hydraulic functions[7]. From the land users' point of view a high groundwater level, a non-uniform pattern of soil fertility and extensive weed growthare consequences of former extended irrigation that is still maintained in some areas.

These conditions motivate irrigation scheduling in order to prevent percolation of irrigation water from the root zone to the groundwater. This was demonstrated successfully for the research sites in Spain, Russia and Ukraine. The use of wastewater, if controlled for salinity, was shown to provide an alternative resource for irrigation to saline groundwater without negative effects on soils and crops in the research sites in Russia, Ukraine and Greece.

Water scarcity
Fresh water is scarce in all study areas. This relates to biophysical conditions (availability of fresh water resources, climate, soils, crops), but also to socio-economic conditions. Fresh water resources are scarce in all studied regions. In Spain this is due to the scarce surface water resources and the overexploitation of aquifers. In Greece and Russia groundwater is available even at shallow depth, but the quality is bad due to the use of saline water for irrigation in previous periods, or due to sea water intrusion. The unawareness of farmers of the effects of unlimited irrigation with saline water also contributes to the water scarcity problems in Greece. In Greece, Russia and Ukraine fresh water resources from surface water are at long distance from farmers' fields.

The main climatic conditions inducing fresh water scarcity in the study regions include the rainfall deficit in the summer growing season. In the study regions Ukraine and Spain this situation is exacerbated due to the unreliability of rainfall and the incidence of drought in this period. Soil conditions inducing water scarcity include the sensitivity to structural decay and consequent reduced infiltration due to drop impact from rainfall and sprinkler irrigation in Ukraine, and the water repellent nature of the coarse, sandy topsoils in the Greek study region, leading to reduced infiltration.

Socio-economic conditions leading to water scarcity in the study regions include the unavailability of irrigation system infrastructure at short distance and the cost-benefit ratio of irrigated agriculture, with costs of water supply and operational costs largely surpassing revenues from crop yields in the study regions in Russia and Ukraine. Also, in Russia, water scarcity is maintained

[7] Water retention and soil hydraulic conductivity characteristics.

because farmers are not stimulated to modernize irrigation techniques and to increase the efficiency of irrigation in agriculture. This is induced by the regional policy, which subsidizes the energy used for the transport of water from the Volga River to fields.

The use of wastewater for irrigation provides a logical water saving strategy in response to the mentioned problems of water scarcity, since treated waste water is increasingly available in the studied regions year-round at shorter distance to agricultural areas than fresh water resources in parts of the study regions. If waste water treatment plants are present, the quality of irrigation water is more easily controlled than if the water is pumped from aquifers or directly withdrawn from surface water bodies. The availability of wastewater and possibilities for treatment were outside the scope of the Water Reuse project, but would require further research for a more detailed assessment of the benefits of wastewater irrigation in response to the problems of water scarcity in the studied regions. The use of wastewater for irrigation may be supplemented with irrigation scheduling, mulching and amendments with clay or surfactant to improve the water use efficiency of crops and/or the wetting properties of the soil surface and topsoil, as was shown for all study regions.

Low crop productivity
Problems with low crop productivity motivating the introduction of water saving strategies are partly related to soil conditions, and partly to land management and economic conditions. The soil conditions refer to the inhomogeneous permeability of fields in Saratov region, which cause similar patterns in crop productivity, with sub-optimal yields on spots which are too dry and too wet. The land management conditions refer to the sub-optimal application of crop rotations and practices related to tillage, weeding, and the insufficient use of fertilizers and pesticides, which is the case in the study region in Ukraine. Low crop productivity is not so much of a problem in the Spanish study region, considering the large economic productivity of irrigated agriculture, which is about five times higher than that of rainfed agriculture (Plan Nacional de Regadios, 2009). In the study region in Ukraine, the lack of credits and resources (fertilizers and equipment) are responsible for low crop productivity. In the study region in Greece, the revenues from crop yields are considered low by land users due to the low crop prices.

Water saving strategies like irrigation scheduling, mulching and amendments of clay or surfactant help to homogenize the wettability of soils under crops or grass covers, as was shown for the experimental sites in Russia and Greece. The use of nutrient-rich wastewater for irrigation was shown to solve nutrient deficiencies by improving crop yields in the research site in Ukraine.

6.1 Biophysical conditions motivating the introduction of water saving strategies

The biophysical conditions influencing the applicability of the water saving strategies investigated in the Water Reuse project include land use and terrain conditions, soil characteristics, agro-climatic conditions and water-related conditions. Of the biophysical conditions relevant to the implementation of water saving strategies, agro-climatic conditions and soil texture, soil fertility and topsoil organic matter content were considered important in all environmental settings of the study regions by researchers and land users. Least important for the applicability of water saving strategies were considered factors expressing the relief of the terrain: the altitudinal zonation and landforms.

With regard to land use and terrain conditions, the applicability of the strategies using irrigation water decreases with application at higher locations in the landscape and at steeper slopes, due to difficulties in the accessibility of irrigation water and increased risks for surface runoff and erosion, especially in the sites with medium- to fine-textured soils (Spain, Russia, Ukraine).

The soil types on which water saving strategies were trialled in the Water Reuse project require irrigation for crop production for various reasons, which include the low moisture retention capacity (Spain, Greece) or the periodic lack of soil moisture in dry seasons (all sites). Especially the Chernozems and Kastanozems soils in the study areas in Russia and Ukraine are potentially rich soils, but the periodic lack of soil moisture is the main obstacle to high yields. In these soils, careful irrigation scheduling is required not only to prevent irrigation water loss, but also to prevent ablation and erosion.

Soil texture appeared to be a critical criterion for the effectiveness of the tested water saving strategies to reduce irrigation losses or to apply wastewater as an alternative source. This relates to the infiltrability and water holding capacities of the soils, the binding capacity for nutrients and toxic substances, and the susceptibility to the development of water repellency.

With regard to soil fertility, the low to medium fertility of the soils examined offers scope for irrigation with wastewater due to the potential of nutrients contained in wastewater to increase crop production and decrease fertilizer application. Positive effects from wastewater use on crop yields were indeed observed in the study areas in Russia and Ukraine on respectively alfalfa and corn and wheat. Effects on the development of water repellency, as often reported in the literature for sandy and loamy soils if the wastewater has high contents of dissolved organic matter, were not observed in the field trials in the Water Reuse project. The results for Greece even suggest that the use of wastewater may even reduce water repellency in already water repellent soils

The good soil drainage and infiltration capacity of the soils in the research areas favors the applicability of wastewater irrigation, provided that the quality of the water is controlled to prevent groundwater contamination due to percolation. This can be prevented by combining wastewater irrigation with proper irrigation scheduling and mulching.

The medium to high soil water storage capacity in the study areas appeared to be favourable for all strategies targeted in the first place at increasing the soil moisture content of the root zone (irrigation scheduling, irrigation with wastewater, use of surfactant and claying). This was confirmed by the results of the field trials in several sites by the observed increased delivery of water to soil depths accessible for plant growth and increased soil moisture contents in the root zone compared to control situations.

With regard to agro-climatic conditions, irrigation scheduling proved to be beneficial for the project's objectives to resolve problems with crop water stress during the dry period of the year and indirect effects on crop water status through decreased infiltration capacity of soils (Russia) and soil water repellency (Greece).

The water-related conditions of the study areas reveal that all strategies are applicable in situations where the groundwater is rather deep (between 5 and 50 m), which also explains the need to reduce water loss from the root zone. Where groundwater tables are less deep during parts of the year, like in the study area in Greece, care should be taken that the root zone may experience a soil moisture deficit due to the large permeability of the soil. Water saving strategies based on irrigation are less useful here; instead strategies aiming at improving the wettability of the soil are more appropriate.

The results of the Water reuse project show that the scarcity of fresh water resources for irrigation, either due to depleting groundwater bodies or the limited availability of surface water, together with the poor quality of the groundwater and surface water in several areas increase the applicability of water saving strategies, and especially irrigation with wastewater as an alternative source.

6.2 Implications for the selection of water saving strategies for an area

The results of the field experiments of the water saving strategies in the Water Reuse project showed that the combinations of land use and terrain conditions, soil characteristics, agro-climatic conditions and water-related conditions in the studied regions in Spain, Russia, Ukraine and Greece were generally favourable to support the objectives of the Water Reuse project to better employ soil wetting characteristics and reduce irrigation water losses, and to use wastewater as an alternative resource for irrigation. In particular the use of wastewater for irrigation was favourable in terms of impacts on the environment (human health and soils), though fertilising effects were only observed in the study area in Ukraine. Areas offering scope for applying the tested strategies based on biophysical conditions were identified in this report.

Several particularities in the combination of the biophysical conditions and implementation of the water saving strategies require attention in the selection of water saving strategies for an area:

- In areas similar to the study area in Spain, possible adverse effects from the use of wastewater from secondary treatment on crop growth and soil wetting characteristics require further research. It is therefore recommended that the use of wastewater from municipal sources of different quality in combination with different soil types in the semi-arid regions of Spain is given more consideration in future research.
- In areas similar to the study area in Russia, care should be taken in applying wastewater irrigation not to increase the risk of deteriorating soil hydraulic properties if sodium-rich water is used on land with shallow saline groundwater in medium-to fine textured soils, low in organic matter content.
- In regions belonging to the former Soviet Union, particular attention should be paid to the risk of inappropriate irrigation scheduling due to the use of outdated irrigation technologies. Under these conditions, it is recommended that wastewater irrigation is combined with irrigation scheduling to keep the root zone at soil moisture contents corresponding to (minimum) crop water requirements, while at the same time preventing percolation of wastewater from the root zone to the groundwater, and on the other hand capillary rise of saline groundwater to the root zone.
- Irrigation scheduling in combination with mulching will be effective in areas with soils with a non-leaching water regime, and sensitive to structural decay due to drop impact from sprinkler irrigation. This applies to areas with biophysical conditions similar to the study areas in Spain and Ukraine.
- Care should be taken in applying water saving strategies based on irrigation (irrigation scheduling and wastewater irrigation) on sloping terrain and application of the strategies in combination with irrigation water supply by channels, due to the risk of soil erosion and the removal of mulch by overland flow.
- Strategies to reduce or prevent the development of soil water repellency (use of surfactants and clay) are likely to be effective in situations where coarse textured, water repellent soils occur in a semi-arid environment with limited rainfall and a long dry period, and limited availability of fresh water resources. The Water Reuse project demonstrated positive effects of these strategies in olive trees with a grass undercover, but many other crop and vegetation types have been reported in the literature to be associated with water repellent behaviour of

soils (e.g. Doerr et al., 2000), and may therefore be suitable for the application of claying and surfactant amendments.

- The biophysical conditions of a region influence the accessibility of irrigation water (either fresh water or wastewater), and should be taken into account in designing irrigation management plans for a region. Where fresh water resources are either scarce or at long distance, wastewater offers an alternative resource, provided that treatment plants for wastewater from municipal, industrial or agricultural production sites (e.g. pig farms, olive mills) are in the proximity, and transport infrastructure is available. Where target areas are in physically isolated positions with limited access to either fresh water or wastewater, like on the Greek isles, the use of commercial surfactants offers scope.
- The use of surfactant and claying were not tested in the study areas in the Russian Federation and Ukraine, and therefore no results are available of these strategies reflecting the biophysical conditions in these areas. Considering the relative novelty of these strategies and their successful reports in the literature (e.g.), it may be useful for future research in water saving strategies to include trials with surfactant and claying in these or similar areas.

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