SIXTH FRAMEWORK PROGRAMME
PRIORITY [INCO calls for Western Balkan countries (FP6-2002-INCO-WBC–1)]

[C.1. ENVIRONMENT, 1.1. Integrated management of regional water resources planning and policy]

Contract for:

SPECIFIC TARGETED RESEARCH OR INNOVATION PROJECT

Final Report

Project acronym:
WATERWEB (WATER resource strategies and drought alleviation in WEstern Balkan agriculture)

Project full title:
Water Resource Strategies and Drought Alleviation in Western Balkan Agriculture

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Executive summary

Strategic objectives

- to contribute to development in the Western Balkans (WB) by introducing strategic water management for drought alleviation and sustainable agricultural practices in the WB,
- to establish and reinforce research expertise in the WB in a range of technologies for water and crop management.

The project has fullfilled its objectives in all workpackages, as described in details in the four annual reports. In this final summary report is reported the main results from the project in each work package. The investment, installation and data collection from the hydrological equipment and the creation of GIS databases for the Land-Water-Economy Information System (LWEIS) is an important tool to introduce appropriate irrigation systems in the WB region. Although there was no permanent N contamination of irrigation water, periodic increases of N in Serbia originating from sewage leakage was alarming. Also contamination of vegetables was detected, induced by washing with channel water containing *E. coli* and *Salmonella*. Different decontamination procedures of the crops included disinfection by UV or organic solutions, however, prevention of contamination is preferred. In Macedonia all water samples were seriously contaminated with *E. coli*, and therefore they could not be used for any purpose. Modern methods for detection of pathogens and other contaminants in water, and technologies for reducing contamination impact, will be of importance in the WB region, where legislation and implementation of EU standards targeting water for irrigation is low. New methods and more focus on the subject of water, as gained through Waterweb, will help to improve existing quality criteria for water for irrigation in Serbia and Macedonia.

Climate predictions for Serbia and Macedonia are an increase in drought events, which will increase their dependence on irrigation and especially on techniques for more efficient water use, such as deficit irrigation (DI). Further investigations of DI techniques will favour agricultural production in Western Balkan. Implementation of DI, for instance partial root zone drying (PRD), in various crops (tomato, potato, grapevine, maize) have the potential to save water, increase water use efficiency, improve end product quality, and reduce the risk of leaching of nutrients. Field studies under various climatic and soil conditions, and knowledge of drought sensitive stages of each crop are needed in order to optimize the strategies.

Farms supplying foreign-owned buyers are noticeably larger (mean of 16.45 ha) than those supplying domestic buyers (6 ha). It was demonstrated that these small-scale producers in Serbia risk being marginalised into low-value markets. One option as a new crop for Macedonia and probably Serbia could be quinoa, which has a high nutritional value, with a high content of protein, a perfect amino acid balance, and a high level of a range of vitamins and minerals. It makes it interesting as a new crop for high quality food in Macedonia and in Europe in general. The water reform has stimulated a significant increase in cost recovery rates, and now a majority of farmers in Macedonia have joined a water community.

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WP 1 - WATER-QUANTITY

Hydrological equipment was installed at three sites in Western Balkan: Radmilovac experimental station of the University of Belgrade (Serbia), 7th July farm (Serbia) and Ovce Pole (Macedonia). Various hydrological parameters were collected, which together with the GIS data were transformed and adapted for the Land-Water-Economic Information System (LWEIS) database. Links built in between the GIS base maps and these data allow visual interpretation.

An important graphic tool used was the ChemGraph which reduces the time needed for chart making, improves visual presentation of data, simplifies data organization, makes error-free work possible, and makes work easier for inexperienced users. ChemGraphs can be used when it is necessary to plot charts within the ArcMap program.

The hydrology data showed that the Radmilovac soil was nearly saturated, with small variations of the groundwater level, due to low permeability. The quantity of water in the stream Šugavac passing through Radmilovac is small, and the quality of both the surface and the groundwater is poor. Therefore, water is not suitable for irrigation on the experimental farm.

New hydrological expertise in WP1 will have a long term output for the WB partners. During 2007 was started an implementation of GIS and hydrological monitoring technologies in southeastern Srem that is a region much larger than Radmilovac. This area is an important agricultural region covering 90000 ha without efficient irrigation systems. Digital maps of the Srem region and a GIS data base were prepared. This will help in introduction of appropriate irrigation systems in Srem.

WP 2 – WATER QUALITY

Deterioration in quantity and quality of water resources, particularly groundwater, represents a problem in many places of the world. Mismanagement of groundwater resources, such as over-pumping, inappropriate land use practices and waste disposal, are the main factors affecting this valuable resource.

Chemical contamination

Nitrate (NO_3^-) represents the most common contaminant introduced to groundwater systems from growing anthropogenic sources. Poor agricultural practices related to N fertilizer applications, irrigation, livestock waste disposal and virgin land cultivation are the most extensive sources of NO_3^-. The easy transport and later conversion of nitrate into N in groundwater might promote surface water eutrophication and threaten human, livestock and the environment. High nitrate levels have been implicated in infantile methaemoglobinaemia and gastric cancer.

Although denitrification is a prominent process in the N cycle occurring in soil, denitrification in aquifers is a much more recent research topic. The maximum acceptable concentration in drinking water is recognized by WHO as 50 mg NO_3^-/l or 11.3 mg N/l). We studied the current situation of nitrate groundwater pollution in the PKB 7th July farm area, particularly after fertilizer applications, and whether the denitrification process in the farm groundwater system is a natural mechanism to eliminate nitrate pollution. 57% of water samples at the farm had nitrate levels above WHO water quality standards, and levels up to 230 mg NO_3^-/l were determined. Water quality analyses of the groundwater indicated an anthropogenic source of pollution. High concentrations of Ca_2^+, Mg_2^+, NO_3^- and SO_4^{2-} reveal the polluted nature of the groundwater due to the application of chemical fertilizers $(NH_4)_2SO_4$ and (Ca, Mg)CO_3. Analysis of data that include chemical composition of groundwater at farm PKB "7. Juli", showed that water quality at the experimental field was not recommended for irrigation, because of HCO_3^- toxic effect.

Three years measurements showed that water in Šugavac and in the wells of Radmilovac was not contaminated with NO_3 or NH_4 (measured concentration were lower than 30mg/l), because of low application of fertilizers in Radmilovac during the past decades. The origin of some periodic increase of N (up-stream Šugavac in July) may be connected to urban runoff and uncontrolled sewage leakage from the houses on top of the hills.

In Macedonia water samples were collected from four basic points into the drainage canal and one extra point in river Azmak, near the experimental field. Test points for chemical characteristics included: I - the upper part of the channel before an animal farm; II- the upper part of the channel downstream of the cattle farm; III - at the trial fields, IV - in the river Azmak upstream of the confluence with the drainage channel, monitoring contamination coming from the upstream village of Erdzelija; V - In the river Azmak, positioned downstream of the drainage channel, used to determine whether contamination from the small drainage channel (points I-III) influenced water quality of the river Azmak, which is the main river draining the Ovce Pole region; VI - irrigation water source used for the maize trials. Chemical analyses of water included measurements of NO_3 and NH_4 according to standard procedure.

Table 1. NO_3 content (mg/l) in different water samples during 2006 (5 – 225mg/l)

Sampling points **date**	I	II	III	IV	V	VI
28.4		17		46		
11.7	<5	<5	<5	166	35	<5
27.7	<5	<5	<5	152	38	<5
8.8	<5	<5	<5	34	32	<5
18.8	<5	<5	<5	15	12	<5
28.8	<5	<5	<5	140	66	<5

No increased concentration of NO_3 or NH_4 have been recorded in the drainage channel adjacent to our trial field (points I-III), much higher concentrations were recorded in the river Azmak taking water from the village of Erdzelija (points IV and V) (Tab. 1).

Increases of NO_3 concentration are likely to be due to the decomposition of organic matter (mainly reeds) growing in large amount in the river Azmak. During the winter period the reed dries and freezes and releases NO_3 as it gradually decomposes. Although testing point V also registers increased concentration of NO_3, a certain dilution of the concentration is evident due to mixing of the water with the small drainage channel. No N contamination of groundwater was seen (testing point VI).

The concentration of NO_3 in the water used for irrigation from the Bregalnica system are under the limits of measurement with the RQ flex i.e. they are very low (under 5mg/l for NO_3 and 20mg/l for NH4). This indicates that water in the Bregalnica irrigation system has satisfactory quality for irrigation. The good water quality used for irrigation is due to the fact that the Bregalnica irrigation system originate from the Kalimanci dam supplied from the small rivers and springs in the mountainous eastern part of Macedonia, considered as environmentally clean. This confirms the fact that the Kalimanci dam does not accumulate naturally polluted water and that there are no outflows into the reservoir of industrial waste water.

Microbial contamination

One aim was to investigate the consequences of microbial contamination on some food products and to test different washing strategies to remove bacterial contamination of these crops. Microbial contamination of fruits and vegetables and the behaviour of enteropathogens in the phyllosphere was studied. Consumption of fruit and vegetable products is commonly viewed as a potential risk factor for infection with enteropathogens such as *Salmonella* and *Escherichia coli* O157, with recent outbreaks linked to lettuce, spinach and tomatoes. Routes of contamination are varied and include application of organic wastes to agricultural land as fertilizer, contamination of waters used for irrigation with faecal material, direct contamination by livestock, wild animals and birds, and postharvest issues such as worker hygiene. The ability of pathogens to survive in the field environment has been well studied, leading to the implementation of guidelines such as the Safe Sludge Matrix, which aim to limit the likelihood of viable pathogens remaining at point of sale. The behaviour of enteropathogens in the phyllosphere has been the subject of research in this project, and our results suggest that inclusion in phyllosphere biofilms or internalization within the plant augments the survival.

Worryingly for the consumer, there is a dichotomy between point of sale survey data and outbreak instance. Overall, surveys suggest a low incidence of contamination. The regulations imposed on growers and the demand for comprehensive hazard analysis and critical control point (HACCP) strategies should prevent any environmental contamination reaching the consumer, however, these approaches do not fully prevent contamination remaining at point of sale. The fact that outbreaks linked to fruit and vegetable products can and do occur indicates that these outbreaks are the result of occasional contamination events, which are difficult to identify and control. At present, the food industry relies on postharvest interventions to limit the number of enteropathogens present on fresh produce. The use of sanitizers, especially chlorine-based products, is an area of media interest and consumer concern, and chemicals cannot be used in organic production. Preventing contamination therefore is a preferred strategy. To influence the survival of bacteria in the phyllosphere, we need to better understand the behaviour of bacteria on the leaf surface, their interactions with other microbes and the host plant, and the potential for internalization. Improved understanding of these areas will lead to new methods to limit enteropathogen survival on food crops.

The contamination of vegetables was induced by their washing with naturally contaminated channel water or with artificially contaminated water (with *E. coli* and *Salmonella*). Different decontamination procedures of these contaminated crops included disinfection by UV or organic solutions (wine vinegar, apple vinegar, vinegar and citric acid). The degree of contamination and success of decontamination was analyzed on the basis of number of pathogenic bacteria.

Microbiological results showed that storing vegetables in channel water had an effect on number of total and faecal bacteria. Transmission of bacteria from contaminated water to the vegetable depended on vegetable species. The greatest effect was found in tomato, the smallest in cucumber. Decontamination procedure for lettuce, contaminated with *E.coli*, showed differences in the efficiency of applied solutions to eliminate pathogens. The most efficient disinfection procedure was treatment with citric acid during 30 min. (Fig. 1). Similar effect was not obtained with lettuce contaminated with *Salmonella*.

The effect of UV treatment was not so efficient in reducing number of pathogens in apples and lettuce as was treatment with organic acids. These results showed differences between tomato, apple and lettuce reaction to UV decontamination procedure. The most efficient UV procedure was for disinfection of tomato fruits contaminated with both *E.coli* and *Salmonella*.

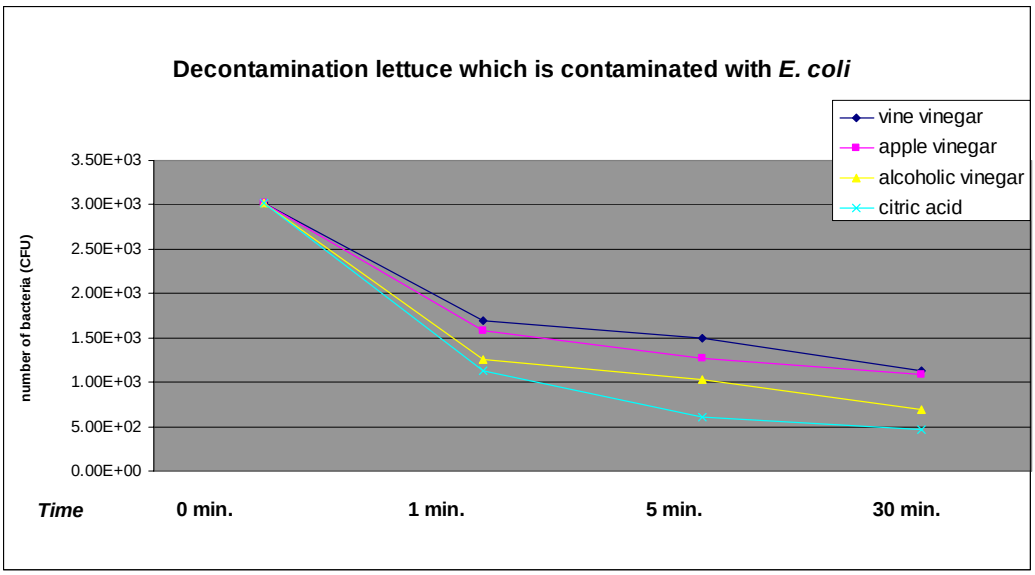

Figure 1. Effects of different organic solutions on number of bacteria in lettuce contaminated with *E. coli*.

The data demonstrated that some organic solutions, such as citric acid or vinegar, could be efficient in disinfecting contaminated fruits and vegetables. Disinfection procedures were not expensive.

In the field of Macedonia, concentration of bacteria increased during the summer in all sampling points (particularly I, II and III) except the irrigation water source. These increases of bacteria were particularly seen in August, probably as a result of the increased temperatures and reduced quantity of water in the channel, providing conditions for intensive growth of the bacteria (Tab. 2).

Table 2. Total number of bacteria (22^{o}) in water measured in water samples (2006)

Sampling points **date**	I	II	III	IV	V	VI
11.7	190	380	210	220	1970	60
27.7	205	410	213	208	2330	70
8.8	2416	1450	2250	130	280	60
18.8	2310	1818	1261	590	1900	80
28.8	2256	3940	716	1157	2640	90

All water samples (except point VI) were seriously contaminated with E. coli (class V). Therefore, they could not be used for any purpose. Bacterial concentrations in the water in the drainage channel varied according to the testing points and occasions. These variations are due mainly to the effect of faecal sewage from the cattle farm near the trial field, because the cattle farm dumps faecal sewage close to the channel, and the climate conditions, with increased temperature and reduced channel flow during the vegetation period. Of the five sampling occasions, water flow in the drainage channel was lowest on 28 August, and this corresponded with the highest levels of bacteria at all sampling points. In this period, the much higher concentrations of bacteria were probably due to the higher temperatures.

Ecotoxicology

Ecotoxicological analyses were based on zooplankton and zoobenthos for saprobity index, and gill histology, with the aim to characterize water sources from Radmilovac. In all water sources, water quality using zooplankton and zoobenthos was mainly in the II class. Occasionally, in open wells,

water quality was between classes I and II, and in Šugavac exit occasionally in class III. Thus, Šugavac water quality had a higher saprobity index being generally more polluted than water of open wells. Saprobity index obtained using zooplankton and zoobenthos organisms varied, but within the range of the II class of water quality. The level of organic pollution was moderate. Changes of gill structure indicated mild and reparable alterations.

Results showed that water from all four sources was moderately polluted. Thus water could not be used for irrigation of crops without treatment, especially for irrigation of vegetables which are used fresh. However, these water sources could be used to supply water to ponds for carp, a fish species sufficiently resistant to these levels of pollution.

The outcomes of the project regarding establishment of modern methods for detection of pathogens and other contaminants in water, and technologies for reducing contamination impact, will be of special interest for the local consumers and growers. Since the legislation and implementation of current EU standards targeting water for irrigation in Serbia is low, this will also help to improve existing quality criteria for water for irrigation in Serbia and Macedonia.

WP 3 – WATER USE

Drought is one of the most common environmental stresses that may limit agricultural production worldwide. Climate model projections suggest a general increase in temperature together with drier conditions in the south and centre of Europe (IPCC, 1998). The Western Balkan region is already suffering from drought, and the climate predictions are for the intensity, frequency and duration of these droughts to increase. Serbia is a region rich in natural resources including water for irrigation, but because of financial difficulties in the last decades much of the irrigation system has fallen into disrepair, particularly around the Danube flood plain (at least 75% out of use). In 2000, about 188000 ha in Serbia were covered with irrigation systems, though irrigation is regularly practiced on only 30000 ha, that is 3% of total agricultural land.

By analyzing drought parameters and irrigation, it was shown that it is possible to use current irrigation systems, with a detailed monitoring of biological, meteorological and soil factors, and to adjust irrigation calendar and irrigation rates to the daily water balance model. On "7. July" farm it was seen that even old systems can, with a skilled approach and some investments, give satisfying results. The problem with this kind of system is the necessity of manual assistance during the irrigation season. The irrigation system was constructed in 1980 on 2000 ha, but today covers only 600 ha. The efficiency of water use is estimated to be 70%, which is average for this type of irrigation system. The time of irrigation was determined according when soil moisture reached 60% of field capacity. Irrigation rate (usually are 30-60 mm) depends on soil type and rooting depth. The application of the daily water balance model in irrigation management has various positive effects on drought mitigation: Rational water utilization; irrigation according to the calendar of drought stress beginning, with optimum irrigation rates; high efficiency of contemporary irrigation systems and satisfying efficiency of old systems; and improvement of irrigation model by analyzing previous irrigation experience.

In Macedonia there are potential water resources to irrigate about 60% of total arable land of approximately 665000 ha. Irrigation schemes constructed over the years cover an area of 163693 ha, of which about 124000 ha can effectively be irrigated (Vasilevski et al., 2000). The level of irrigation efficiency showed a decrease from 65% in 1987 to 31% in 1995, and the trend for decreased efficiency is expected to continue because of unfavourable climatic conditions during the

growth season. A reduction of area under irrigation has also occurred because of administrative and operational difficulties, as well as farmer reluctance to pay water charges.

Recent results demonstrated that alternate and partial root zone drying (PRD) is an irrigation method with potential to decrease agricultural water use. With this technique half of the root zone is irrigated while the other half is allowed to dry out. The treatment is then reversed, allowing the previously well-watered side of the root system to dry while fully irrigating the previously dry side. In comparison with conventional irrigation methods, PRD is a relatively simple technique that requires only the adaptation of classical irrigation systems to allow alternate wetting and drying of part of the rootzone (FAO, 2002). The PRD field results from different parts of the world demonstrated that in addition to the benefit in terms of reduced vegetative growth, and consequent improvement of fruit quality, the benefit comes also in the form of improved water use efficiency, in some cases almost a doubling (Davies et al., 2000; Dos Santos et al., 2003).

PRD is a novel irrigation technique for the Western Balkans. Together with EU partners the PRD method was tested in tomato, grapevine and maize, with results on yield quantity and quality, as well as water use efficiency. Cost benefit analyses was also done with the aim to establish the agronomic and economic implications of this water saving irrigation strategy.

Tomato

In tomato, fresh weight yield was similar for all treatments, whereas there was c. 30% higher fruit dryweight of PRD compared to FI. Water use efficiency data (amount of fruit produced per unit of water used) showed significant increases of deficit irrigation techniques (especially PRD). The content of organic acids and sugars of importance for the sensory quality of the tomato were not significantly different between treatments. There were positive effects of other important tomato quality characteristics, such as lycopene and antioxidant activity (Tab. 3).

Results for different tomato varieties (data not shown) indicate that genotypic differences in tomato reaction to PRD which could be the result of different sensitivity to PRD-induced chemical signals. Research concerning genotypic differences in tomato response to PRD is now in progress.

Table 3. Studied traits of tomato grown under partial root drying (PRD), regulated deficit irrigation (RDI) and full irrigation (FI).

Traits	FI	PRD	RDI
Fruit FW (kg/plant)	2.2±0.2	2.6±0.2	2.6±0.2
Fruit DW (g/plant)	52.1±7.5	75.7±3.2	73.5±6.5*
WUE (g fruit DW /dm^{-3} H_2O)	0.6±0.1	1.7±0.1***	1.5±0.1***
Sugar content (%)	5.1±0.3	5.1±0.3	4.7±0.2
Organic acid content (mg/g FW)	19.6±0.6	19.9±0.9	20.1±0.6
Lycopene content (mg/kg FW)	6.2±0.5	4.2±0.2**	8.9±0.4**
Antioxidant activity (mmol TU/g FW)	1.66±0.13	2.54±0.19*	2.18±0.23

* , ** and *** presented significant differences of at P< 0.05, P< 0.01 and P< 0.001

Grapevine

The Mediterranean region of Europe is particularly prone to drought and potentially vulnerable to the expected climatic changes. In the last years the number of rainless days has increased dramatically in the South of Europe (Luterbacher et al., 2006), and this tendency is expected to continue in the future (Miranda et al., 2006). Therefore, irrigation and the use of species and

varieties adapted to the new climatic conditions will be needed (Chaves & Oliveira, 2004). Water use efficiency will become a key factor for the sustainability of one of the major crops in the region, the grapevine. The predicted increase in air temperature will accelerate grapevine phenology, leading to a reduction of the vegetative and reproductive periods.

In Portugal was seen an inverse relationship between leaf temperature and stomatal conductance, which was stronger after noon, when stress is more pronounced, indicating that leaf temperature measurement is a good method for a fast detection of drought stress (Grant et al., 2007) (Fig. 2).

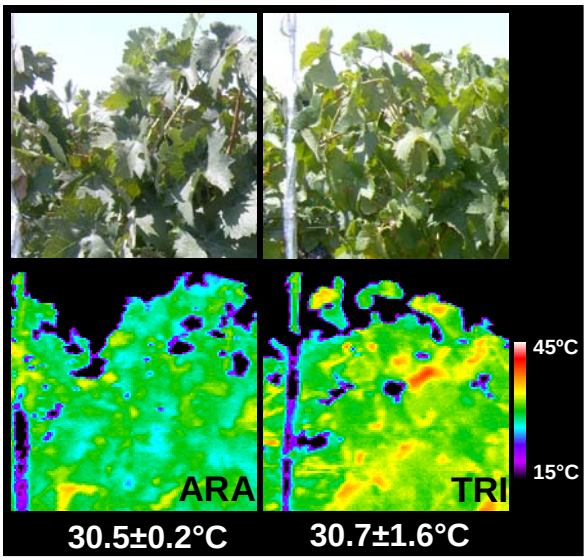

Figure 2. Visible and false colored IR images of the canopies of the cultivars Aragonez (ARA) and Trincadeira (TRI).
Images were taken with an IR imager (IR Snapshot 525, 8-12 μm detector) on 9 August 2007 (air Tmax= 36.8°C, air RHmin=13%). Temperature values are averages calculated for the sunlit side of the canopy ± SE (n=3 to 4 plants).

Droughted or non-irrigated (NI) plants presented lowest yields. The low berry weight of NI berries resulted from the low soil water content and the high berry temperatures, which led to berry dehydration and a reduction in division and expansion of berry cells (McCarthy, 1999). The higher yield in the irrigated treatments was mainly due to the increase in volume and weight of the berries. It was demonstrated that an irrigation up to 30-40% of ETc was sufficient to guarantee maximum yield allowed by the Portuguese agricultural department for grapes (14 t/ha) to produce wine of high quality. With full irrigation (FI) was obtained yields of 20 t/ha which induce a lower berry quality. With the deficit irrigation treatments were reduced water applied while maintaining a production of good quality.

Cover cropping appears to be an important tool to control plant vigour allowing the farmer to spend less money with canopy management and at the same time improving the cluster microclimate.

In grapevine in Serbia there was a slight reduction in yield for deficit irrigation treatments, but water use efficiency (WUE) was almost doubled in PRD and RDI compared to FI (Tab. 4). Berry quality parameters such as total soluble solids and titrable acidity were significantly higher in RDI. PRD presented significantly higher values of total antioxidant activity. Deficit irrigation could be a useful strategy to save irrigation water and to improve the quality of important quality characteristics such as antioxidant activity.

Table 4. Studied traits of grapevine grown under partial root drying (PRD), regulated deficit irrigation (RDI) and full irrigation (FI).

Traits	FI	PRD	RDI
Yield (kgDW/vine)	1.72±0.03	1.54±0.04*	1.65±0.09
WUE (g fruit DW /dm^3 H_2O)	34.48±0.62	64.30±1.64***	68.87±3.93***
Total soluble solids (% DW)	25.28±0.24	25.88±0.13	26.83±0.36*
Titrable acidity (tartaric acid g/gDW)	11.019±0.48	10.80±0.49	13.50±0.49**
Antioxidant activity (mmol TU/g DW)	12.48±0.51	13.78±0.26	10.67±0.86*

* , ** and *** presented significant differences of at P< 0.05, P< 0.01 and P< 0.001

Maize

Maize is widely grown in the WB region, but yields at Ovče Pole are low without supplementary irrigation (4t/ha). When irrigated, it yields up to 12 t ha^{-1}. The highest average yield 13.14 t/ha was obtained from FI treatment, 13% higher than PRD50 and 10% higher than PRD70. The small deviations from FI was due to higher efficiency of water use by the plants. The lowest yield was drought treatment (6.9 t/ha), 47.8 % lower than FI. WUE increased 55% with DI, but almost doubled by using PRD. With decreased amount of water the protein content in the grain increased, from 8.00% with FI to 8.16% with PRD70 and 9.47% without irrigation (Tab. 5).

Table 5. Qualitative characteristics of maize (%)

%	FI	PRD70	PRD50
Starch	71.54	71.67	71.62
Proteins	8.00	8.16	8.13
Oil	3.37	3.35	3.43
Absolute mass	397	390	373

The study of the implementation of PRD techniques for irrigation of three crops in Serbia and Macedonia (tomato, grapevine and maize) showed an increase in irrigation water use efficiency, maintenance or improvement of yield quality, and a slight decrease in yield (10-20%). Results from different PRD treatments (PRD70 and PRD50) in maize showed that it is important to continue with investigation of irrigation at different crop growth stages.

Economical analyses of maize production showed increase in profit in PRD70 irrigated maize. Similar increase in profit in PRD treated tomato or grapevine was not achieved. In Serbia the price of water is low and, therefore, the participation of water for irrigation in the cost of production of tomato and grapevine is small.

However, climate predictions for Serbia and Macedonia are an increase of drought increasing dependence on irrigation and especially on these techniques that allow more efficient use of water. There is an increased market demand for crops with higher nutrient values. Therefore, we expect that further investigations of PRD technique will benefit agricultural production in Western Balkan.

Quinoa

Quinoa was sown to study the possibility for its introduction in a dry region of Macedonia, Ovce Pole. At the beginning of the project two locations were used (chernozem site and salty site) and 10 varieties from South America and Denmark. After two years, investigations were continued with the Danish material on normal soil, with and without irrigation. The salty site was also sodic, and not suitable for any production of crops. Average results for quinoa grown in Ovce Pole were 499 and 255 kg/ha (rainfed) and 744 and 591 kg/ha (irrigated) for KVL37 and KVL52, respectively.

Irrigation increased yield in both cultivars (Fig. 3). Quinoa has a high nutritional value, with a high content of protein, a perfect amino acid balance, and a high level of a range of vitamins and minerals, which makes it interesting (Jacobsen, 2003; 2007).

Figure 3. Quinoa experimental field in Ovce Pole, Macedonia (2007)

Potato

In potatoes, the production of root originated xylem ABA under field soil drying and PRD were described and quantified (Liu et al. 2006a), and water use in pot grown potatoes under PRD and DI irrigation treatments was compared (Liu et al. 2006b). Water saving and water use efficiency (WUE) was of similar magnitude when PRD50 treatment (50% of FI) was compared with DI50 (Liu et al. 2006b). Similar results have been obtained in tomatoes in pot experiments (Savic et al. 2008). It was also found in pot grown tomatoes that under high evaporative demands the PRD70 irrigation significantly improved WUE as compared with the DI70 irrigation (saving 30% of water as compared to FI).

The main results of the field experiments on sandy soil using PRD70 and DI70 are:

1. The time interval of shifting irrigation side in the PRD treatment can be based on actual evapotranspiration amount of the FI treatment. This method for shifting should be defined for different soil types and climate conditions.
2. The PRD treatment should be applied after tuber initiation until maturity only. During the early growth stages, the PRD and DI treatments decrease growth and tuber yield of the plants.
3. Of the investigated water saving irrigation strategies (PRD50, PRD70, DI), PRD70 from end of tuber initiation until maturity was the only water saving irrigation strategy able to maintain yield and significantly increase WUE.
4. PRD70 increased significantly the amount of marketable tubers with a diameter of 40-60 mm as compared with FI.
5. PRD70 improved soil nitrogen availability late in the growing season maintaining top greenness to a greater extent, as compared with PRD50, DI and FI. This effect might have contributed significantly to the continued tuber filling late in the growing season resulting in yield maintenance and improved tuber size distribution.

A simple mechanistic model to predict ABA signalling of potatoes exposed to PRD was developed (Fig. 4). Sustaining a significant ABA signalling, thereby inducing partial stomatal closure during PRD, is essential for optimizing the irrigation strategy by reducing water use and maintaining yield. The fact that potatoes regulate leaf conductance (g_s) via ABA production in the root system was established previously (Liu et al. 2006a). The g_s regulation as a function of xylem $[ABA]_{xylem}$ is shown in Fig. 4 obtained from combining greenhouse and field experiments.

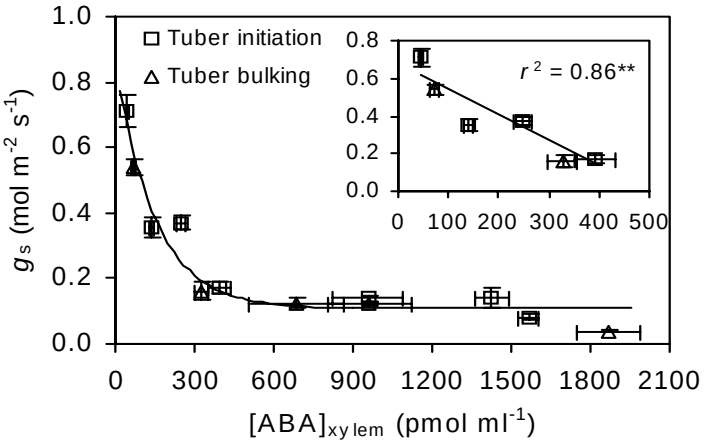

Figure 4. Stomatal conductance as a function xylem $[ABA]_{xylem}$ (Liu et al. 2006a).

Impact of variation in the quality and quantity of irrigation water

A general model linking climatic and edaphic factors and their impact on plant growth through modification of the pH of the shoot apoplast were presented. We propose that environmental factors that affect roots (drought, flooding, salt stress, nutrient availability) will interact with climatic and other factors that affect the aerial parts of the plant (e.g. PFD, temperature, VPD, diurnal and seasonal change, and fungal infection). This interaction will occur via changes in the ABA signal perceived by the guard cells and the growing cells of the leaf. The pH of distinct regions of the root, stem and shoot, each perhaps responding locally to differing levels and types of stimuli and perturbation, will govern the amount of ABA that becomes "locked away" in these localities, or that is free to travel on to the responsive cells at the culmination of the transpiration stream in the leaf apoplast. Perturbations that increase the pH of a particular region will amplify the ABA signal as the transpiration stream traverses it (Fig. 5). Such interactions between ABA and pH allow the shoot to modify the response to a root signal as a function of local conditions. It is necessary for the leaf to be dynamically linked to the aerial environment because of the potential for dehydration, and this may be especially important in tall plants (like maize) where leaves are much further away from the root and where a root signal may take hours or days to travel to the shoot. Preliminary results show that stomata of several species are competent to respond to an increase in apoplastic pH induced by a foliar spray to the intact plant, even when soil drying does not alkalise xylem sap from the same species.

Water quality will significantly affect plant physiological responses to deficit irrigation, with high N status of irrigation water sensitising the responses of stomata (gas exchange) and leaf growth to soil drying. The final impact of deficit irrigation with water of variable quality will depend upon air temperature and evaporative demand. A fundamental understanding of the mechanistic basis of physiological and developmental responses to deficit irrigation will be necessary if we are to accurately predict the impacts of plant management in circumstances where water is scarce, of variable quality and where climate varies throughout the growing season.

Compared to classical furrow irrigation, PRD and RDI could be useful strategies to save irrigation water without significantly sacrificing yield with positive effects on quality. The expertise in new deficit irrigation techniques is new for the Western Balkans and was build on collaborative research with EU partners in WATERWEB. Application in the future to a wide variety of field-grown crops will allow assessment of the potential scientific and practical impact of such new technologies on a large scale. If a water saving of 25% can be obtained, this will have a large potential impact on agricultural production in the WB.

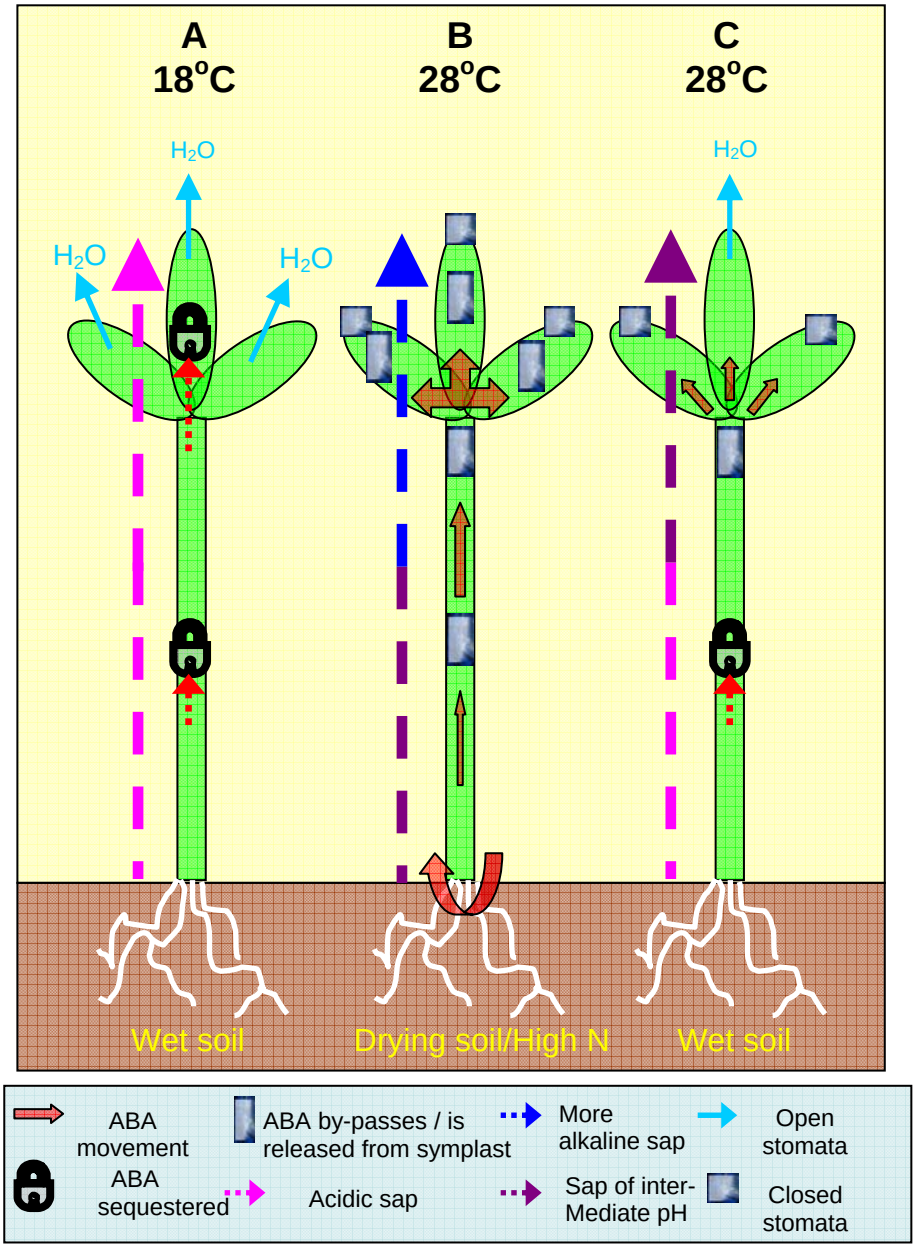

Figure 5. Diagrammatic representation of the effects of the rhizosphere and the aerial microclimate on xylem and apoplastic pH in the different regions of the plant, and on modulation by pH of ABA translocation/sequestration within and between the different plant tissues/organs.

The ABA concentration finally perceived by the stomata is thus representative of the entire plant environment via effects of the environment on pH. Stomata respond to this ABA concentration by adjusting their aperture and controlling water loss (Modified from Wilkinson and Davies, 2008).

Deficit irrigation techniques are based on the knowledge of crop reaction and adaptation to drought and, therefore, will also help in increasing expertise in crop stress physiology. This expertise is missing in the WB region, but it is essential for reducing the negative effects of drought in agricultural crops.

WP 4 – WATER ECONOMY

Work on the economics of agricultural water management had two main parts: (a) cost benefit analysis of alternative technologies and crops, and (b, c) institutional and survey analysis of agricultural water management systems in Serbia and Macedonia.

(a) Cost Benefit Analyses

Cost benefit analysis of alternative technologies and crops were done with the aim to compare the effects of PRD and RDI with conventional irrigation practice and to establish the agronomic and economic implications of these water-saving irrigation strategies. Economical analyses of tomato and grapevine showed that PRD and RDI techniques had no profit gain compared to FI. The explanation is that currently in Serbia and Macedonia the price of drinking and industrial water is low and does not cover the expenses of water exploitation. Serbian government compensates this difference between price of exploitation and consumption and the participation of price of water in total price of crop production is low and varied from 3% to 6%. Currently the profit of agricultural production of these and other crops depends mainly on yield and not on the quantity of water for irrigation or on the quality of food.

However, climate predictions for Serbia are that drought intensity will increase and this will increase agricultural dependence on irrigation and, especially, on these techniques that allow more efficient use of water. Also, there is an increased market demand for crops with higher nutritive value. Therefore, further investigations of PRD and RDI techniques in different crops will be beneficial for agricultural production in the Western Balkans.

Expertise gained in the project allowed a new approach in socio-economical assessment of water-management and irrigation procedures. Attempts to improve strategic management of water resources for Serbia and introduction of new, more efficient techniques for irrigation have to be coupled with a detailed understanding of the economics of water management. Thus, stakeholders need to have proper cost-benefit analyses of the new strategies developed as deliverables from the WATERWEB project.

In Macedonia interviews were carried out on Water Associations and farmer representatives around the Bregalnica irrigation system. Pilot farmer questionnaire were prepared for socio-economic analyses of 150 farmers. GIS technology was used to digitise maps with basic parameters for Water Associations, and links made to spreadsheets and farmer questionnaires databases (Fig. 6).

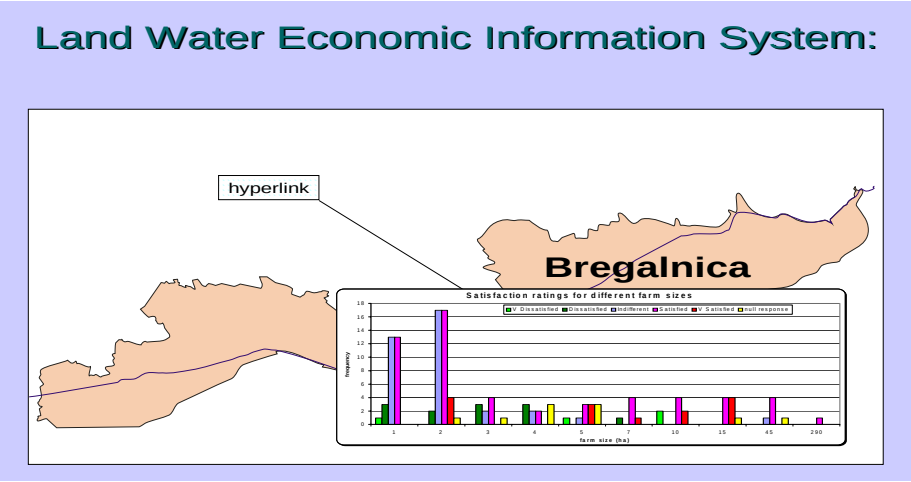

Figure 6. LWEIS

Maize

Farmers in the Ovce Pole region use mainly furrow irrigation in maize. Interviews were made with farmers who usually produce maize, using the traditional way of maize irrigation (TI). Interviewed farmers were located around the Bregalnica irrigation system.

In the traditional way of production, the number of maize irrigations is often 3-6 times, and water quantity is not measured. The farmers in Water Associations (WA) are paying a lump sum price of 5760 den/ha (94.12 EUR/ha). For cost-benefit analysis of the TI treatment, yield data are those provided by the farmers who were interviewed. For the TI furrow treatment, typical farmer yields are 8.5 t/ha, with an average of 10868 m^3 water/ha used by farmers, which means 21% more water compared to the FI treatment and 111% more water compared to DI50. Farmers who practised treatments with controlled irrigation water use had a higher profit than with TI irrigation. The analysis of maize showed that the highest profits were obtained with PRD70 irrigation technique, increasing profit compared with traditional irrigation by 31.9%, and PRD70 by 40.6%.

Quinoa
The initial analyses showed that quinoa is financially justifiable, due to its high price (1.5 €/kg) and the increasing demand for high quality food in Macedonia and in Europe in general.

(b) Institutional and survey analysis of agricultural water management systems in Serbia.
The analysis in Serbia was conducted drawing on in-depth interviews with key policy actors and Serbian farmers on their water and environmental management practices, together with an analysis of secondary data. Overall it is concluded that Serbia is poorly positioned to implement both domestic and European environmental policy. Interview analysis revealed widespread disregard of the regulation of water use and general cynicism towards officials and agencies responsible for water management and pollution control, which are chronically under-resourced. The practical enforcement problems identified are unlikely to be addressed by the focus in the EU accession process on legal transposition of the acquis and the approximation of national laws.

The main findings from the Serbian farm survey are:

- The majority of farmers lack faith in the current regulatory system.
- Basic rules on extraction of water are not followed by the majority of Serbian farmers: for example only 6 out of the 26 farmers that reported that they extract river water had a license to do so.
- Water quality and quantity are concerns for farmers but are not considered to be the most pressing problems, particularly compared against low prices and meeting the requirements of buyers.
- The environmental problems of poor water quality are general to Serbia. Farmers identify water quality and pollution as issues, albeit not the most important.
- There is some willingness to pay extra for cleaner water, with this willingness being positively linked to whether farmers see water quality and quantity as a problem, and their degree of financial stress.
- Contracting is, overall, rather poorly developed with quality control rudimentary. This is further depressing farm-gate prices. For example, less than two thirds of farmers in the sample sell under any form of contract and where contracts are used they very rarely stipulate environmental standards.
- Foreign owned buyers of fresh fruit and vegetables employ much stricter environmental controls and standards. This will have important implications as Serbia's market is opened up via the process of Europeanization and greater penetration of foreign direct investment.

Survey work in Serbia has focused on agricultural water management in the economically important fresh fruit and vegetable sector. This sector is highly dependent on a supply of suitable water, and

work has focused on the extent to which farmers face water management problems and the degree to which private and public environmental standards are being enforced at the local level. To this end, a representative survey of commercial fresh fruit and vegetable farmers in the Grocka municipality (close to experimental station Radmilovac) and the rest of Serbia was conducted as part of the WATERWEB project. In total, 165 survey responses were collected.

Survey evidence indicates that implementation of public environment standards is very poor in Serbia. For example, according to the 1991 Water Law, farmers should possess a permit or licence for water extraction from rivers, streams, bore holes and, in certain circumstances, from natural springs and wells. Survey data (Tab. 6) indicate that this is occurring only in a minority of cases. The collective impact of unregulated extraction on water resources is highly significant.

Table 6: Water use by farmers and possession of a licence for extraction

	No. farmers without appropriate licence	No. farmers with license for extraction
River or stream extraction	24	6
Bore hole	19	6
Natural spring /wells	15	1
Mean farm size (ha)	6.21	6.77

The difficulty of implementing state environmental regulation in Serbia is severe. On average the 13 farmers with licences sold 46% of their output on contract (with a private buyer) compared with only 20% for those with unauthorised water use. This suggests a potential linkage between private sector contracting and adherence to state legislation. However there are no significant differences between those without and those with licences in terms of farm size (the means for the two groups are 6.2 and 6.8 ha respectively).

Farmers' beliefs regarding the Serbian state's ability to effectively regulate agri-environmental issues were also elicited. Respondents were asked to rate the degree to which they agreed with statements on a five-point Likert scale. Farmers have strikingly little faith in the regulatory system in Serbia, and only 5.4 % of respondents agreed or strongly agreed with the statement that 'water use is effectively controlled by the state' (Tab. 7). A similar lack of confidence is evident regarding the control of farm pollution and the use of agri-chemicals.

Table 7. Farmers' opinions of the effectiveness of the Serbian regulatory system

	Rating of agreement/disagreement with statement (% of all responses)				
Statement	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Water use is effectively controlled by the state	52.7	29.7	12.1	4.8	0.6
The use of agri-chemicals is effectively controlled	46.1	35.2	13.9	3.6	1.2
Farm pollution is effectively monitored	40.0	33.3	23.0	3.0	0.6
Agricultural polluters are fined when they break the law	42.4	21.8	31.5	2.4	1.8

Overall there are 8 farmers in the sample who on average 'agree' or 'strongly agree' with the statements in Table 2. These eight farmers are not significantly larger in size than the rest of the sample but do sell a significantly higher proportion of their output on contract (40%) compared to the rest of the sample (13%).

Regarding the implementation of private environmental standards, farmers were asked about the behaviour of buyers and any regulations enforced concerning the use of pesticides and water testing. Results are disaggregated to compare those selling to domestic and foreign buyers with the former group split between those with and without a contract (all those supplying a foreign owned buyer had a contract). In less than 5% of cases is the main buyer foreign-owned. Firstly considering the whole sample, the most salient private regulation is at the point of supply: 16.4% of buyers reject produce in poor condition; but only one in ten buyers tests for contaminants. Fewer than 11% of farmers are required to keep a pesticide log. However only 5.5% are directed as to what agri-chemicals to use and only 4.8% have their water quality tested.

Significant differences are apparent depending on the type of main buyer. Private regulation is almost entirely absent for farmers supplying domestic buyers without a contract. These farmers are selling via spot (wholesale) markets without guaranteed prices, and buyers do not interfere with agricultural practices. This type of buyer also does not provide any credit, physical inputs, training, transportation, loan guarantees, machinery, specialist on-farm storage, or investment to farmers. In contrast all foreign buyers reject produce that is in poor condition. Those who supply domestically-owned buyers with a contract lie between these extremes. A gradient of rising private regulation is therefore apparent from domestic wholesale markets to domestically-managed contracts and then contracts with foreign-owned buyers. In terms of the involvement of buyers in production practices, the greatest jump is between domestically-oriented contracts and those with foreign-owned buyers.

Farms supplying foreign-owned buyers are noticeably larger (mean of 16.45 ha) than those supplying domestic buyers either with or without a contract (means of 6.07 and 5.76 ha respectively). Small-scale producers in Serbia risk being marginalised into low-value markets.

(c) Institutional and survey analysis of agricultural water management systems in Macedonia.
Research work in Macedonia has focused on evaluating the success of the introduction of Water Communities (WCs) for managing local irrigation systems in the Bregalnica region. This area is semi-arid with crop production being highly dependent on irrigation. During the 1990s the infrastructure for irrigation deteriorated sharply and the level of cost recovery was poor. The introduction of WCs combined with a project for rehabilitation of the infrastructure led by the World Bank has attempted to introduce sustainable, local self-management for irrigation systems. Our research has focused on assessing the effectiveness of these new institutional arrangements. Data on the performance of the WCs were collected via two methods. Firstly, in-depth interviews were conducted with the president or a senior member of the control board of selected WCs. Secondly, survey work was conducted with farmers and in total, 249 responses collected through face to face interviews in the field.

As part of the farm survey, respondents were asked to rate their degree of satisfaction with their WC, on a five point Likert scale. Only 2.5 % were ‘very dissatisfied’ with the majority being either ‘indifferent’ or ‘satisfied’. The introduction of WCs has been neither an unqualified success nor resounding failure. Regarding cost recovery, results are more positive. For the first two years following formation of the WCs average cost recovery rates, measured as the percentage of billed amounts actually paid, were 72 and 70.6 % respectively. This compares favourably with the comparable figure of 36 % prior to formation. However, significant non-payment persists.

There are significant differences between individual WCs, which are reported for the six most numerous WCs included in the sample in Fig. 7. Overall farmers in Trkanje register the highest mean level of satisfaction (3.75) with the lowest scores for Istibanja (2.89). The differences between the six WCs are significant at the 5% level.

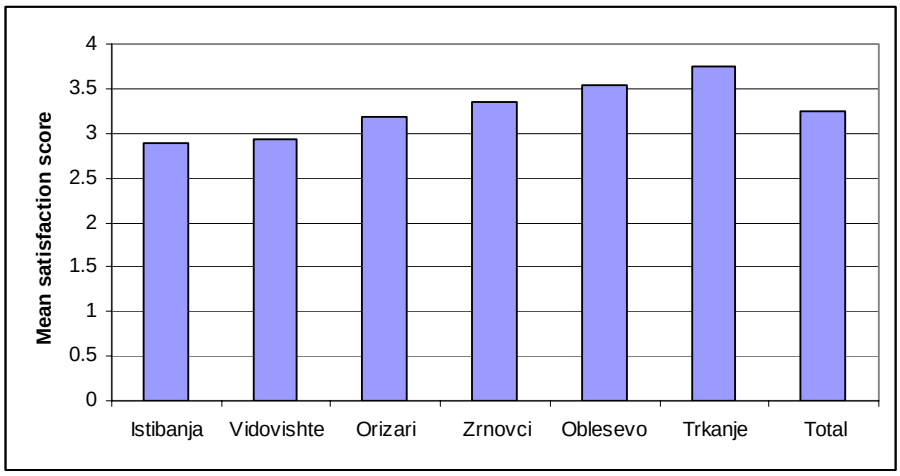

Figure 7. Mean Satisfaction Scores by WC

The descriptive statistics indicate that even with a common external framework, significant variations in the performance of WCs are evident, suggesting the importance of variations in internal characteristics for explaining variations in satisfaction. These factors were explored in the econometric models, which focused on the decision of farmers to join a water community (Heckman selection probit model), determinants of farmers' satisfaction with their membership of WCs (ordered probit model) and factors associated with changes in farmers' water payment behaviour (non-parametric CLAD model).

Factors identified as important in the decision to join a water community (Heckman selection probit model), only size of farm is significant. Factors identified as important determinants of members' satisfaction with their WC (ordered probit model) showed that membership satisfaction is related to household characteristics, the WC's performance and the technology employed in the case of flood irrigation. The analysis of determinants of changes in farmers' payment behaviour (non-parametric CLAD model) is critical to assessing the viability of WCs, given historically low levels of cost recovery and the objective of WCs becoming financially sustainable local institutions.

Overall the analysis indicates that more optimistic inferences are warranted than Theesfeld (2004), who, based on analysis of irrigation systems, concluded for Bulgaria that 'it remains questionable whether measures that facilitate local self-governance can be successful…. The general attitude toward collective action is pessimistic'. In neighbouring Macedonia, by contrast, the majority of farmers in project areas have joined a WC, less than 20 % are either dissatisfied or very dissatisfied with their WC and the water reform has stimulated a significant increase in cost recovery rates.

WP 5 – WATER DISSEMINATION

The official kick-off meeting of the project was held in Belgrade in April 2004, hosted by the Faculty of Agriculture, with representatives of the Ministry of Agriculture, Forestry and Water Management, Ministry of Ecology; University of Belgrade; non-governmental organizations (NGO); and members of different interest groups. The following days, the members of Consortium visited experimental fields in Serbia (Radmilovac, PKB farm "7. Juli"- Surčin) and Macedonia (Ovče Pole).

The annual meetings have taken place in Lancaster in February 2005, in Lisboa, Portugal, July 2006, and in July 2007 in Viborg and Copenhagen, Denmark, linked to the Conference on Water Productivity in Agriculture and Horticulture - How can less water be used more efficiently? The final meeting was held in Skopje, Macedonia, 10-11 December 2007, and in Belgrade, Serbia on 13 December 2007.

The priority of the project has been involvement of stakeholders, and discussions and transfer of project results to farmers, municipal and government officials, scientists and consumers. Therefore several stakeholders meetings have been held.

The project has produced a large amount of publications, in total 43 scientific papers, 79 conference presentations and 3 popular papers. Presentations at conferences were given 28 times, and 20 posters have been displayed. In addition, various meetings and media briefings were held, and radio and TV interviews given.

The WATERWEB project reinforced existing expertise of the Faculty of Agriculture of Belgrade in the area of sustainable water management. Improvements of scientific capacity and experience in international co-operation allowed the faculty to get two new EU projects:

1. CROPWAT-A Centre for Sustainable Crop-Water management (FP6-2004-INCO-WBC-SSA-3, No- 043526)
2. ROSA –Reinforcement of sustainable aquaculture (FP7-REGPOT-2007-3, No 205135).

A FP7 project application is submitted (SMARTWHEAT) and four proposals for national research projects. All these activities are long-term output of the WATERWEB project and they will ensure long-term expertise of WB partners in crop water saving technologies.

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