SWUP-MED Project

Sustainable Water Use Securing Food Production in Dry Areas of the Mediterranean Region

Work Package 1

***Deliverable* 1.3:** Conclusions and recommendations for improving farming systems

Due date of deliverable:	60 months
Authors:	Ouafae Benlhabib (IAV) and Sven-Erik Jacobsen (UCPH)
Contact for Queries:	Sven-Erik Jacobsen University of Copenhagen (UCPH), Denmark; E-mail: seja@life.ku.dk
Dissemination Level: ***Pu****blic*, *Restricted to other Programmes Participants*, ***Re****stricted to a group specified by the consortium*, ***Co****nfidential only for members of the consortium*	PU
Deliverable Status:	Revision 1.0

Project funded by the European Commission within the Seventh Framework Programme

Executive summary

The Mediterranean cropping systems are commonly exposed to harsh abiotic stresses; they are generally characterized by cereal-fallow and cereal monoculture rotations, poor crop management, low and decreasing soil fertility, production instability and low yield. The rainfed system is the most important in the Mediterranean countries and most smallholder farmers are reliant on rainfed agriculture and grow mainly cereals.

Crop production and its sustainability require an integrated management that sustains land productivity. Thus, the cropping practices have a direct impact on nutrient and water availability, and also on soil structure and fertility. To improve land productivity and its sustainability in rainfed Mediterranean systems, a number of crop management practices could be recommended.

Trials that were carried out by farmers highlighted different effects of crop rotation, climate proof crops and cultivars, reduced tillage, manure, supplemental and deficit irrigation on crop production, soil fertility and structure, and water availability. Field tests confirmed at time positive effect of crop rotation on the next crop growth and productivity in Bouchane; quinoa and chickpea had a beneficial effect on wheat grain yield in one of the farmers' trial. In Turkey however, the four years of the rotation study did not show significant effect of previous crop on wheat yield and yield components. In Syria, also there was no effect of the rotation in the soil nutrient; there was no significant variation in total nitrogen concentration in soil between rotations. Improvement in nutrient availability status of the soil under legume and quinoa might be a long-term process, which may take several years.

Significant crop yield improvements were more evident through the use of climate proof crops and cultivars, and through suitable soil and water managements. Recurrently, yield and total land productivity increased when crops, soil and water were well managed; the production improvement under farmers' cropping conditions went over the 10% of the project expectation.

As general synthesis to the SWUP-Med field and experiment work, the main sustainable cropping practices to recommended to farmers in the semi-arid rainfed Mediterranean regions are the use of crop rotation, climate proof crops and varieties, reduced tillage, organic manure, supplemental and deficit irrigation and also the use of treated wastewater (Benlhabib et al. 2013; Yazar et al. 2013), Hirich et al. 2013, Jacobsen et al., 2012).

Introduction

The strategic objective of the SWUP-Med project was to improve food crop production under the Mediterranean regions that are subjected to the multiple abiotic stresses. In its work package 1, the project addressed directly farmers' communities by introducing and testing adapted technologies and strengthening a diversified crop rotation through suitable crop, soil and water managements. WP1 Farming systems carried activities in farmers' fields throughout participatory research, focusing on the entire farming system, and practices that are related to the optimization of the land productivity, water use efficiency and the crops adaptation to the local climate.

The cropping system SWUP-Med coordinator (Dr. Ouafae Benlhabib) has an agronomic background and plant selection and breeding as field of specialization. Since year 2000, she has the responsibility of the quinoa selection program. As faculty at the "Institut Agronomique et Vétérinaire Hassan II, Rabat", she has involved several graduate students and technicians in the SWUP-Med project activities and has been publishing papers with SWUP-med partners and students (in the list of references). By combining between both programs objectives, the SWUP-Med project activities were linked to the quinoa selection program through the evaluation of advanced lines in the farmers' plots and tutoring farmers in quinoa cultivation and seeds production.

The improvement of the Mediterranean cropping systems has focused on three main cropping components that are the soil, the crops and the water.

The present WP1 delivery (last) aims to report the main conclusions and recommendations of the cropping systems project activities and to hand over suggestions on technologies that are able to improve the dryland productivity and sustainability in the Mediterranean region.

I. Soil management

Tillage is the main tool controlling the root zone, soil structure and fertility, and water retention. Unfortunately, conventional cropping systems evolving along with increasing energy inputs and mechanization have often reduced biological biodiversity and increased risk and instability (Pearson et al., 1995). The cropping systems have turned into a highly vulnerable ecosystem.

Minimum and no-tillage is the best option under water limiting condition (Mrabet et al. 2002). Using the adapted plowing tools e.g. the spring tine cultivator (shallow tillage) instead of moldboard plowing (deep tillage), reduce water losses by evaporation and soil disturbance. Under farmer's trial in Bouchane, bread wheat total biomass and grain yield were higher with reduced tillage treatment than the control. Although the plants grow taller with more shoots under conventional tillage, reduced tillage plants produced more seeds per spike (23 versus 17), larger seeds (49 versus 42 mg/grain), higher biomass (2.5 versus 2.0 t ha^{-1}) and grain yield (1.8 versus 1.5 t ha^{-1}) (Benlhabib et al. 2013). In a very dry year in Morocco, grain yield in a no-tillage system was 100 and 72% higher than the conventional management and fall chisel plowing (Bouzza, 1990).

Conservation tillage and other erosion-control practices minimize loss of nutrients, in particular phosphorus that is attached to the soil. Nutrient management aids in using nutrients wisely for optimum economic benefit, while minimizing the environmental impact. In general, it is difficult to define the correct fertilizer dose. Soil tests are useful to determine deficiencies of nutrients such as phosphorus and potassium. It is more difficult to determine nitrogen needs in advance, but nitrogen recommendations based on crop yield can be pursued.

By applying mineral fertilization at annual rate basis and accordingly to the crop requirement, N losses through denitrification and leaching are minimized or totally avoid.

Soil fertility can be significantly improved through the use of organic manure, since most semi-arid Mediterranean soils are deficient in organic matter, and manure is produced on most farms. Manure is an excellent source of plant nutrients (N, P, K). In Bouchane, in one farmer trial, results showed clearly the dominance of the organic fertilized plot over the control for most barley yield components: number of spikes/ha was 345 10^4 versus 187 10^4, biomass 4.6 versus 1.9 t ha^{-1}, and grain yield 2.6 versus 1.1 t ha^{-1}, an increase of 233% l (Benlhabib et al. 2013).

Incorporating crop residues in the soil is an efficient management tool, which together with reduced tillage improves rainwater absorption, slows runoff and minimizes evaporation. It also maximizes soil water storage and crop water use efficiency. The incorporation of crop residues has positive effects on crop yield by increasing soil water retention and content and subsequently reducing nutrient leaching (Smolikowski *et al*. 1997; Mrabet et al. 2002; Silvertown *et al*. 2006). In most semi-arid regions, major obstacles to crop residue management are the removal of cereal straw for livestock and stubble grazing.

Management recommendations to improve soil structure

R1. Conservation tillage will minimize nutrient loss and soil erosion. As the vegetation is not disturbed and well established there is a net decrease in soil loss.

R2. Conservation tillage will improve soil structure due to fewer disturbances and hence a net improvement of soil aggregate stability.

R3. By leaving at least 30% residue cover on the ground soil erosion is reduced and soil stability improved.

Management recommendations to improve soil water holding capacity

R4. Conservation tillage improves rainfall infiltration, and reduces runoff and soil evaporation

R5. Conservation tillage improves rainwater conservation in the soil and increase crop water use and water use efficiency

R6. Organic manure improves soil water retention capacity.

Management recommendations to improve soil fertility

R7. Frequent soil tests will help to decide which field needs nutrient applications, and at what rate.

R8. Best timing of nutrient application is important.

R9. Compost and animal manure will improve progressively the nutrients in the soil.

R10. Crop residue and legumes incorporated in the soil will increase soil fertility. Leave at least 30% on the soil surface.

II. Crop management

Alternating crops that have different nutrient requirement, root shape and length, and nitrogen fixation capability, influence positively soil structure and fertility. Cereal-legume and cereal-quinoa rotations improved nutrient availability status of the soil; however, it takes years to improve the soil quality and to reach the sustainability of the cropping system.

The best yield increase was at Bouchane, Morocco, where chickpea- wheat (CP-W) and quinoa-wheat (Q-W) rotations produced 230% more wheat than the cereal monocrop. Chickpea and quinoa rotations with wheat also produced 80 and 60% more biomass. Yield increase was less when wheat was rotated with corn.

At an experimental station in Turkey, the effect of previous crop on wheat and chickpea yield and yield components was not significant during four year rotations study (Yazar et al. 2013). When rainwater and mineral fertilization are not limited, the rotation effect is less pronounced in the short term.

The introduction of climate proof varieties and crops is an important solution to increase the productivity in many harsh environments. The improved material has shown continuous increases in yield.

Drought tolerant wheat genotypes are in general characterized by earliness, short size, and high water use efficiency. Sharma et al. (2012) reported that under dry environments high yielding wheat genotypes matured early, were short to medium in size and had medium to high 1000-kernel weights.

Several improved cereal genotypes were compared to a local variety, used as a control. In a comparison between a barley improved cultivar (Massine) and the local farmers' variety, the local variety surpassed the improved cultivar through its higher biomass (2.2 versus 1.2 t ha^{-1}) and grain weight (31.7 versus 27.0 mg). Barley local variety is suitable for both animal feed and grain production. Barley cultivars exhibit large adaptation and yield stability across different agro-climatic zones. Barley as a marginal crop is usually growing in less favorable environments, on subsistent farms mostly having financial limitation. The use of improved and certified cultivars is totally absent. Farmers use to practice mass selection and to produce their own seeds that they frequently share with neighbors.

Two trials were conducted to test bread and durum wheat genotype effect. Cultivars performed differently. Mehdia bread wheat cultivar ranked first; it had an average of 3.5 spikes/plant, 49.0 grains/spike, 3.11 t ha^{-1} biomass, and 2.4 t ha^{-1} grain yield. Salama, which ranked last, developed on average 1 spike/plant, 24.90 grains/spike and produced 2.15 t ha^{-1} as total biomass, and 1.22 t ha^{-1} as grain yield. In durum wheat, no significant variations were found in grain yield among cultivars; grain yield fluctuated between 0.71 and 1.33 t ha^{-1}. Tarik and Karim cultivars displayed however the best plant growth under rainfed cultivation. Significant genotype variation was found in the number of grains/spike (18.58 to 35.68) and the spike density (150 10^4 to 241.60 10^4 spikes/ha).

Genotypic variations were also reported in grain legumes. ICARDA drought tolerant accessions of faba bean, chickpea and lentil proved to have high yield potential compared to local cultivars in Portugal, Morocco and Syria. In Portugal, ILC588 and ELIXIR chickpea genotypes had stable yields across environment (Costa *et al*. 2013). In Syria, Hamwieh *et al*. (2013) screened 16 chickpea genotypes for four cropping seasons (2009-2012) under rainfed and two irrigation treatments (30 and 100% field capacity). They reported significant effect between treatments, years and genotypes. FLIP03-145C and ILC588 genotypes were highly drought tolerant.

In quinoa, L142 accession recorded the highest seed yield (15.1 g/plant) out of five (Filali, 2011). Quinoa accessions were ranked within two groups: group 1 late maturing, low yield and low harvest index; group 2 early maturing, high yield with high harvest index. In Syria, Puno, a cultivar from Denmark, ranked first compared to Titicaca (1 versus 0.7 t ha^{-1}). The same was the case under Moroccan environment at Bouchane in 2011 and Ain Sbit in 2013.

The most cultivated crops in semi-arid regions are cereals, mostly barley. Local barley populations developed through mass selection by farmers are well adapted and largely grown in semi-arid dryland (Azouz, 2009). Barley, bread wheat and durum wheat were grown in 2013 on about 88% of total cropped land in Bouchane, with 45, 31 and 12% (Benlhabib et al. 2013).

Crop management timing is a very important factor for production quantity and quality. Greatest efficiency results when nutrients are applied at sowing or during the early part of the growing season. Proper timing is most important with nitrogen and phosphorus, and less critical with potassium.

Sowing and harvesting dates for size of weed problem. Integrated weed management strategies should be applied using conservation tillage.

Well-timed irrigations provide enough water to prevent crop stress while using water from rainfall. Irrigation scheduling and improving irrigation management can have significant impact on growers' benefits. Water requirements remain high during the early reproductive stages until the dough stage. As the crop approaches physiological maturity more water can be removed from the soil profile without impacting final grain yields. So, determining when to stop irrigating is an important economic decision.

Sowing date can be a useful management tool to prevent some crop diseases. Early or delayed planting may increase, reduce, or not affect diseases, depending on the type of disease. When infection of a disease occurs at the seedling stage, the planting date directly affects the yield. By planting early, crop can escape seedling infections by pathogens that occur in warm soil temperatures. Some pathogens in other cases do not cause much damage if soil moisture is not excessive.

Recommendations for better crop management

R11. Crop rotations will improve rainfall infiltration, soil hydraulic conductivity, and nutrient availability

R12. Climate proof varieties will increase productivity in semi-arid environments. Climate proof varieties and drought resistant cultivars have high yield stability.

R13. Water efficient crops have high potential under drought (quinoa, legumes).

R14. Timing for sowing, manure applications (N, P, K), weeding and irrigation is important. Apply nitrogen (N) as close as possible to the period of rapid crop uptake. Manure application has to be done in the fall.

III. Water management

Irrigation makes agriculture possible in areas otherwise unsuitable for crop production. Globally, agriculture accounts for 80–90% of all freshwater used by humans, and most of that is in crop production.

Deficit irrigation (DI) has been widely investigated as a valuable and sustainable production strategy in dry regions. By limiting water applications to drought-sensitive growth stages, DI aims to maximize water productivity and to stabilize yields. DI requires precise knowledge of crop response to drought stress, as drought tolerance varies considerably with genotype and phenological stage. Modeling crop water productivity should help in developing and optimizing DI strategies. Irrigation management is shifting from emphasizing production per unit area towards maximizing the production per unit of water consumed, the water productivity.

Under conditions of scarce water supply and drought, deficit irrigation should lead to greater economic gains than maximizing yields per unit of water for a given crop. Farmers are more inclined to use water more efficiently, and more water efficient cash crop selection helps optimize returns. However, this approach requires precise knowledge of crop response to water as drought tolerance varies considerably by species, cultivar and stage of growth. Crops or crop varieties that are most suitable for deficit irrigation are those with a short growing season and are tolerant to drought (Stewart and Musick, 1982).

Supplemental irrigation (SI) is potentially profitable for small farmers when it is used at critical growth stages. SI has been demonstrated to increase and stabilize crop yield under multiple abiotic stresses. Supplemental irrigation provides higher and more stable yields, lower risk of crop failure, and higher water productivity. On-farm water productivity was 2.5 kg/m^3 under supplemental irrigation, compared to 0.3-1 kg/m^3 under rainfed conditions and 0.8 kg/m^3 under full irrigation (Benlhabib et al. 2013).

Field trials in several countries showed massive increases in wheat and barley yields with small quantities of supplemental irrigation: yields increased from 1.3 t/ha to 3 t/ha in Syria, from 4.6 to 5.8 t/ha in Morocco and from 2.2 to 3.4 t/ha in Iran (ICARDA, 2013). Supplemental irrigation allows farmers to plant their crops early, increase yields and prevent exposure to terminal heat and drought stress in hot areas, and frost in cold areas.

In arid and semi-arid areas, there is a need of an efficient capture and use of the scarce water resources. An optimization of rainfall management, through water harvesting can contribute to improving the small-scale farmers' livelihood by upgrading the rainfed agriculture production.

Rainwater harvesting involves methods that increase the amount of water stored in the soil profile by trapping the rain where it falls (Hatibu & Mahoo, 1999; Stott et al. 2001). Rainwater harvesting is basically a prevention of net runoff from a given cropped area by holding rainwater and prolonging the time for infiltration. This system works better where the soil water holding capacity is large enough and the rainfall is equal or more than the crop water requirement (Hatibu & Mahoo, 1999).

Water harvesting involves land shaping with the construction of contour bands, terraces and ridges (FAO, 1993). Normal designs for semi-circular bands involve making earth bands in the shape of a semi-circle with the tip of the bands in the contour. In Tanzania, soil moisture conservation under tie ridging showed maize yield increase of 47% compared to flat planting. In semi-arid areas in Niger, the highest grain yields in 1999 and 2000 on Zai treatments compared to flat planting has been attributed to a build-up in the soil organic matter contents which may have increased the soil water holding capacity.

Recommendations for better water management

R15. Water use should be minimized by applying only enough water to meet crop needs, by monitoring soil moisture

R16. Efficient irrigation systems to minimize evapotranspiration (drip irrigation)

R17. Deficit irrigation (DI) as irrigation strategy and supplemental irrigation (SI) under rainfed cropping to increase yield and water productivity

R18. Harvest water to reduce runoff and improve rainfall water infiltration and soil conservation.

R19. Integrate crop modeling tools to optimize crop water productivity and develop DI and SI efficient strategies

R20. Non-conventional water sources in fodder crop biomass production should be used, reducing nutrient use and environmental impact.

References:

Azouz Y, 2009. Analyse des systèmes de culture dans deux régions la CR de Bouchane (Rhamna) et la CR de Mnabha (Préfecture de Marrakech) : Le Quinoa comme culture alternative à introduire. Mémoire de 3ème cycle d'Ingénieur d'état en Agronomie, IAV Hassan II, Rabat, Morocco, 88pp.

Benlhabib O, Yasar A, Qadir M, Lourenço E, Jacobsen SE, 2013. How can we improve Mediterranean cropping systems? Submitted to JACs.

Bouzza A, (1990) Water conservation in wheat rotations under several management and tillage systems in semiarid areas. ETD collection for University of Nebraska - Lincoln. The University of Nebraska - Lincoln, 132 pages; Paper AAI9030107.

FAO 1993. CLIMWAT for CROPWAT, a climatic database for irrigation planning and management by M. Smith. FAO Irrigation and Drainage Paper No. 49. Rome.Hatibu & Mahoo, 1999;

Filali K (2011). Caractérisation et évaluation du rendement de lignées de quinoa (Chenopodium quinoa) dans la région de Rhamna. Mémoire pour l'obtention de Diplôme de Master en Biotechnologies et Amélioration Génétique, Institut Agronomique et Vétérinaire Hassan II, Rabat, Maroc, 82pp.

HatibuN. and Mahoo, H., (1999). Rainwater Harvesting Techniques for Agricultural Production: A Case for Dodoma, Tanzania, Sokoine University of Agriculture, Tanzania.
http://www.animaltraction.net/contil/contil-contilhatibu-waterharvesting-TZ

Hirich, A., R. Choukr-Allah, S.-E. Jacobsen. 2013. The combined effect of deficit irrigation by treated wastewater and organic amendment on quinoa (*Chenopodium quinoa* Willd.) productivity. Desalination and Water Treatment 1-6. doi: 10.1080/19443994.2013.777944 ICARDA, 2013. Supplemental irrigation – more crop per drop. Science for better livelihoods in dry areas - http://www.icarda.org/tools/supplemental-irrigation-produces#sthash.m2OFwFuX.dpuf

ICARDA (2013) Supplemental irrigation - more crop per drop, Science for better livelihoods in dry areas. http://www.icarda.org/tools/supplemental-irrigation-produces.

Jacobsen, S.-E., C.R. Jensen, F. Liu. 2012. Improving crop production in the arid Mediterranean climate. Field Crops Research 128, 34–47

Mrabet R (2002) Wheat yield and water use efficiency under contrasting residue and tillage management systems in a semiarid area of Morocco. Expl Agr 38:237-248.

Pearson CJ, Norman DW, Dixon J (1995) Sustainable dryland cropping in relation to soil productivity - FAO soils Bulletin 72.

Sharma RC, Morgounov AI, Braun HJ et al (2012) Yield stability analysis of winter wheat genotypes targeted to semi-arid environments in the international winter wheat improvement program, International journal of plant breeding. In: Global Science Books, 2012.

Silvertown J, Poulton P, Johnston E, Edwards G, Heard M, Biss PM. 2006. The Park Grass. Experiment 1856-2006: Its contribution to ecology. J Ecol 94(4): 801-814.

Smolikowski B, Lopez JM, Querbes M et al (1997) Utilisation du paillage léger et de la haie vive dans la lutte contre l'érosion en zone semi-aride de montagne (Cap Vert). Réseau Erosion Bulletin ORSTOM n°17: 99-110.

Stewart, B.A. & Musick, J.T. 1982. Conjunctive use of irrigation and rainfall in semi-arid regions. Advances in Agronomy 1: 1-23.

Stott, T., Leeks, G., Marks, S. and Sawyer, A. 2001. Environmentally sensitive plot-scale timber harvesting: impacts on suspended sediment, bedload and bank erosion dynamics. Journal of Environmental Management 63: 3-25.

Yazar A, Barut H, Mart D, Aykanat S, Torun MB, Çakır B (2013). Comparison of Wheat-Based Rotation Systems vs Monocropping under Dryland Mediterranean Conditions. SWUP-MED Project Final Conference Proceedings: Sustainable water use securing food production in the Mediterranean Region under changing climate. 10-15 March, 2013, Agadir, Morocco.